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EXXON MINERALS
CRANDON PROJECT

EXXON MINERALS COMPANY, U.S.A.

HOUSTON, TEXAS

CRANDON PROJECT
PYRITE PROCESSING STUDY
SUMMARY

JUNE 1981

2489/03

Davy McKee
ENGINEERS AND CONSTRUCTORS

Davy McKee

2489/3
June 1981

PYRITE PROCESSING STUDY
SUMMARY

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1. SUMMARY

INTRODUCTION

Exxon Minerals Company, is considering the possibility of developing a sulfide ore deposit in Forest County, Wisconsin, near the city of Crandon. The ore deposit contains pyrite along with the valuable minerals which are processed in a flotation mill to make separate concentrates of zinc, lead and copper minerals which will be shipped to treatment facilities to extract the metals.

Normally the waste product from the mill, called tailing, is deslimed. The coarser portion (sands) is returned to the mine as mine fill. The finer fraction is sent to an impoundment area, or tailings pond, for settling of solids and water reclamation. As an alternative to placing the pyrite in the tailing impoundment area, Exxon studied various options such as marketing the pyrite or processing the pyrite to recover sulfur, iron, and minor nonferrous metals in some economical way.

PURPOSE

The purpose of the Pyrite Processing Study is to first determine whether the pyrite can be marketed in its basic form, and, if not, whether other marketable products can be made from it using proven technology.

CRANDON PYRITE

An estimated material balance from the proposed Crandon flotation mill indicates a pyrite flotation concentrate of 3128 MTPD (3440 STPD) split up into two fractions of 2364 MTPD (2600 STPD) of +20 micron pyrite sands and 764 MTPD (840 STPD) of -20 micron materials (slimes). Plans are to use the 2364 MTPD (2600 STPD) of +20 micron materials as mine fill and to study the marketing or further processing of the -20 micron material. The study also includes, as an alternate "A", the marketing or further processing of the total pyrite flotation concentrate of 3128 MTPD (3440 STPD).

Using the slimes portion (-20 micron) of 764 MTPD (840 STPD), the products and quantities that can be made from the Crandon pyrite are determined as follows:

CRANDON POTENTIAL PRODUCTS

BASE CASE

Primary Products	MTPY	STPY
Pyrites (slimes)	267,400	294,500
Sulfur (total pyrites)	134,000	147,400
H_2SO_4 (100%) - pyrites	400,000	440,000
H_2SO_4 (100%) - pyrites + zinc**	720,000	792,000
Iron pellets (65.2% Fe)	180,000	198,000
Liquid sulfur dioxide	267,400	294,500
Secondary Products		
Phosphoric acid (54% P_2O_5)	480,000	528,000
Diammonium phosphates (18-46-0)	562,000	618,000
Gypsum	2,400,000	2,640,000
Supporting Supplies (Requirements)		
Phos rock (32% P_2O_5)*	810,000	891,000
Ammonia (anhydrous)*	125,000	137,000

*The above major supplies are required to produce the secondary products - phosphoric acid, diammonium phosphate and byproduct gypsum.

** 320,000 MTPY from a potential zinc refinery.

Using the available process and the annual tonnages of product, the results of the Pyrite Processing Study are rendered in six volumes:

- o The Marketing Report by Commodities Research Unit Ltd. (CRU)
- o The Transportation Report by Jones, Bardelmeier & Co. Ltd. (JBCo)
- o The Phase I Report by Davy McKee Corp.
- o The Phase II Report by Davy McKee Corp.
- o The Summary Report by Davy McKee Corp.
- o The Appendix by Davy McKee Corp.

CONCLUSIONS & RECOMMENDATIONS

As a result of the marketing study, it was concluded that some of the potential products did not warrant cost studies for various reasons. These products are as follows:

- o Liquid Sulfur Dioxide - Area consumption is far less than Crandon's potential production (Section 3-1).

- o Byproduct Gypsum - Gypsum produced in the manufacture of phosphoric acid contains impurities that are costly to remove. (Section 3.1 and 3.7).

- o Miscellaneous Iron Products - Such as pigments, iron powder, etc., due to lack of markets or production considerations (Section 3-2).

PYRITE CONCENTRATES (Sections 3.2 and 6)

The marketing study indicated two (2) possible market outlets for the Crandon pyrite: Copper Range Company at White Pine, Michigan and Cities Service Company in Copperhill, Tennessee. Copper Range Company could only use 24,000 tons/year, 10% of Crandon's production. Cities Service Company was capable of using all of Crandon's pyrite concentrate production, if they reduced the production of their own mines.

As a result of the marketing study, Exxon approached Cities Service Company to determine the extent of interest that Citgo might have in potential Crandon pyrite production. Upon further investigation by both parties as to the nature of the material and freight rates, Cities Service Company notified Exxon Minerals Company, U.S.A. that they were no longer interested in the pyrite concentrates (see letter dated 11/26/79, M. F. Finfrock, Cities Service Co. to P. D. Garvey, Exxon Minerals Co., U.S.A.).

The final conclusion, based upon the fine size of the material, the high moisture content, the commodity price, and the freight rates of transporting Crandon pyrite concentrate to a process area, is that the market does not exist.

RECOMMENDATION

- o Essentially, no market exists for pyrite, and it is recommended that the coarse portion of the pyrite tailings be used as mine fill, with the fine portion settled in ponds for water reclamation and later reclamation of minerals, if and when, the economics are more favorable.

PROCESS - SULFURIC ACID WITH IRON TO DISCARD (Sections 3.4 and 6)

Roasting of pyrite concentrate to produce sulfuric acid, is a well known highly developed process. However, the transportation costs of shipping the pyrite concentrate to a process center impacts the cost of the sulfuric acid produced to such an extent that it cannot compete with sulfuric acid from burning sulfur.

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PYRITE PROCESSING STUDY
SUMMARY

The projected selling price of Crandon pyrite byproduct sulfuric acid is \$15/metric ton versus the published commodity price of sulfuric acid from burning sulfur of \$35/metric ton. Estimated production costs for sulfuric acid from Crandon pyrite is \$40.04/metric ton. The obvious discrepancy in price is due to the necessity of getting rid of the byproduct acid so that the mining operation is not shut down by accumulating a surplus of acid. The brokers guarantee to purchase the nominal output of the byproduct acid plant at a set dollar price per MT.

RECOMMENDATION

- The production of sulfuric acid using Crandon pyrite at either of the two process centers, Greenbay, Wisconsin and Evansville, Indiana, is uneconomical and should not be considered.

PROCESS - SULFURIC ACID, IRON PELLETS, NONFERROUS METALS & PRECIOUS METALS RECOVERY (Sections 3.5 and 6)

The sulfuric acid costs produced from Crandon pyrite are impacted by the transportation costs to the process center and the revenue received for byproduct sulfuric acid is concluded to be \$15/metric ton as stated above.

The iron cinder, produced in making sulfuric acid from Crandon pyrite could possibly be pelletized and the impurities removed to provide feed for blast furnace operation. The quantity of the pellets involved in this exercise (180,000 MTPY), however, does not warrant the capital intensive installation costs.

The Kowa Seiko process used in removing the impurities in the iron pellets could allow the copper, zinc, lead, gold and silver in the pyrite to be recovered. The credits received from those metals still do not make this product route viable.

RECOMMENDATIONS

- Even with a substantial credit for the nonferrous and precious metals, the impact of the transportation costs prevail and the process route is not economical. Recommendation is that the sulfuric acid and iron pellet production route should not be considered.

PROCESS - DIAMMONIUM PHOSPHATE FERTILIZERS, SULFURIC ACID, IRON PELLETS, NONFERROUS METALS & PRECIOUS METALS RECOVERY (Sections 3.6 and 6)

This process route was developed to provide a use for the sulfuric acid generated in the roasting of the proposed Crandon pyrite and the Crandon zinc refinery to produce diammonium phosphate fertilizer (DAP).

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PYRITE PROCESSING STUDY
SUMMARY

A market exists for diammonium phosphate fertilizer in the Mid West area as well as for the iron pellets and the other metals. The growth rate of DAP is approximately 2% per year.

The logistics of bringing in phosphate rock from Florida or Morocco impacts the production costs, and represents 13% of the production costs.

The disposal of the byproduct gypsum generated in the production of phosphoric acid and DAP may be a greater environmental concern than the disposal of the original fine pyrite tailing.

RECOMMENDATION

- Even though the economics of both the Base Case and Alternate Case A of this product route indicate a positive R.O.I. and may be marginally attractive, the problems associated with gypsum disposal both as to quantity and physical characteristics could impact the environment to a greater extent than the original pyrite disposal at the Crandon mine locations. Therefore, this process route should be subjected to close scrutiny before it is considered viable.

PROCESS - ELEMENTAL SULFUR, IRON PELLETS, NONFERROUS METALS & PRECIOUS METALS RECOVERY (Sections 3.3 and 6)

Elemental sulfur is estimated to be in short supply in the near term. However, by the end of the 1980s, sulfur recovered from power plants, oil refiners, and the like is projected to be in adequate supply.

Elemental sulfur production by roasting pyrite, generating SO_2 gas and converting to sulfur by the Claus process is very expensive and energy intensive. Also, as 70% of the sulfur produced is used to make sulfuric acid for the production of fertilizer, the better and less expensive method would be to make sulfuric acid directly.

The production of sulfur by this method cannot economically compete with Frasch sulfur and other sulfur sources.

RECOMMENDATIONS

- The production of elemental sulfur from pyrite is not recommended due to its high energy consumption and production costs.

RECAPITULATION

The following table summarizes the various routes for processing Pyrite into usable product. Either they are a dead loss or do not approach the minimum return on investment (ROI) deemed necessary in the mining industry.

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PYRITE PROCESSING STUDY
SUMMARY

TABLE 1

RECAP OF R.O.I. ON DISCOUNTED CASH FLOW BASIS

BASE CASE

	Process	Operating Cost	Revenue	Gain/(Loss)	R.O.I.
1.	Sulfuric acid, iron to discard	16,016,000	7,000,000	(10,016,000)	Neg.
2.	Sulfuric acid, iron pellets, non-ferrous reclamation	23,577,600	17,258,975	(6,318,625)	Neg.
3.	Diammonium phosphate, iron pellets, non-ferrous metal reclamation	100,340,000	134,898,975	34,558,175	2.51
4.	Elemental sulfur, ion pellets, nonferrous reclamation	21,308,975	27,890,440	(6,581,465)	Neg.
	ALTERNATE A				
5.	Sulfuric acid, iron to discard	53,835,320	25,410,000	(28,425,320)	Neg
6.	Sulfuric acid, iron pellets, non-ferrous reclamation	73,070,540	70,720,750	(2,349,790)	Neg
7.	Diammonium phosphate, iron pellets, non-ferrous reclamation	269,371,800	391,151,750	121,778,890	5.32
8.	Elemental sulfur, ion pellets, nonferrous metal reclaim	85,135,760	83,231,340	1,904,410	Neg.
	ALTERNATE "B"				
	No Sulfuric Acid from Zinc Plant				
9.	Diammonium phosphate iron pellets, non-ferrous metal reclamation	64,849,000	76,420,000	15,269,725	Neg.

TABLE 1 (Cont'd.)

RECAP OF R.O.I. ON DISCOUNTED CASH FLOW BASIS

ALTERNATE B-1

No Sulfuric Acid from Zinc Plant

10.	Diammonium phosphate, iron pellets, non-ferrous metal reclamation	237,601,174	336,200,750	98,599,576	2.81

PIRCON-PECK AND SULFUR ASPHALT

Introduction

The Pyrite Processing Study is based on state-of-the-art, commercially proven processes. We were aware that the Pircon-Peck process to produce a low grade fertilizer was being researched and had a potential for future use. The same applied to the sulfur asphalt and sulfur cement. It was the opinion then, as now, that much research has to be accomplished to make both of the processes commercial and state-of-the-art.

Pircon-Peck Process

The Pircon-Peck Process is a process that is being developed to desulfurize low sulfur flue gas from power stations and similar operations to produce a low grade phosphate fertilizer for sale. It was reported to be less capital intensive, that a market was available for the fertilizer in the upper Great Lakes region, and that the manufacture of the fertilizer would pay the power company to use their sulfur containing gas. The capital costs and other costs utilized in the literature were over stated and the profit assumed unrealistic.

1. The process requires defluorinated phosphate rock which is not available in quantities and is costly.
2. The demand for low grade fertilizer (7-20-0 and 7-30-0) is minimal. To upgrade the production, 7-20-0, it is necessary to purchase additional phosphoric acid and ammonia to make the proposed 7-30-0 fertilizer.
3. Because of #2 there is no demand for the process.
4. The process is only in the early stages of development with low chances of commerical success in the near term.

Sulfur Asphalt

Sulfur asphalt and sulfur concrete appears to have potential. Both Canada and Texas have been experimenting with these materials with good success. The cost of the sulfur used in the asphalt/cement will dictate its potential. We believe that it will only be used in those areas where sulfur glut exists.

To produce sulfur from a pyrite roasting plant with high oxygen in the gas is energy intensive and capital intensive. Its production should not be considered an economic source of elemental sulfur.

2. PURPOSE & METHODOLOGY

2.1 PURPOSE

The purpose of the Pyrite Processing Study was to determine the following:

- Feasibility of marketing a separate pyrite flotation concentrate without further treatment.
- Feasibility of marketing those primary products which could result from the processing of pyrite concentrates.
- Feasibility of marketing secondary products produced from the further processing of primary products.
- Technical feasibility of producing these products with commercially proven processes.
- The economic feasibility of producing the products that would result in further processing pyrite concentrates.
- Will the further processing of the pyrite concentrates create less, equal, or more concern relative to the environment than the original concern of using tailing ponds?

The study is divided into six (6) volumes: This Summary Report, Phase I Report and Phase II Report, CRU Marketing Report, JBC Transportation Report, and the Appendix. Phase I Report is comprised of three (3) areas of endeavor:

- Marketing (including 320,000 MTPY of sulfuric acid from zinc refinery)
- Transportation of pyrite and pyrite products
- Process Technology & Selection

Phase II Report is also comprised of three (3) areas of endeavor:

- Capital Costs
- Operating Cost
- Revenues

2.2 CRANDON PYRITE CONCENTRATES

The estimated Crandon material balance indicates a pyrite flotation concentrate of 3128 MTPD (3440 STPD) split up into two fractions of 2364 MTPD (2600 STPD) of +20 micron pyrite sands and 764 MTPD (840 STPD) of -20 micron pyrite material (slimes) with a size and chemical analysis as shown in TABLES I and II. It is planned to use the 2364 MTPD (2600 STPD) of +20 micron materials as mine fill and to study the marketing or further processing of the -20 micron material. As an alternate, it is planned to study the marketing or further processing of the total pyrite flotation concentrate of 3128 MTPD (3440 STPD).

If the market for pyrite concentrates in the United States and North America indicates that it can not be profitably disposed of due to its limited usage, location and transporation costs, the study considers what further processing is necessary to make products that might be marketable.

TABLE I

Stringer Pyrite Concentrate - Minus 20 Micron Slime

Particle Size	% Retained Individual	% Retained Cumulative	% Passing Cumulative
+ 29.6 micron	0.4	0.4	99.6
22.9	1.1	1.5	98.5
16.0	12.0	13.5	86.5
11.0	23.0	36.5	63.5
8.5	11.9	48.4	51.6
- 8.5	51.6	100.0	-
Total	100.0	-	-

Specific Gravity 3.97

Massive Pyrite Minus 20 Micron Slime

Particle Size	% Retained Individual	% Retained Cumulative	% Passing Cumulative
+ 21.4 micron	0.3	0.3	99.7
14.9	2.2	2.5	97.5
10.3	18.1	20.6	79.4
7.9	19.1	39.7	60.3
- 7.9	60.3	100.0	-
Total	100.0	-	-

Specific Gravity 4.49

TABLE II

CALCULATED CHEMICAL ANALYSIS OF PYRITE CONCENTRATE

Element	Assay, % Slime (-20 micron)
Fe	43.60
Cu	0.12
Ni	0.0035
Pb	0.123
Zn	0.66
Bi	0.010
Cd	0.0022
Cr	0.0034
Co	0.017
Mn	0.019
Hg	0.0004
Mo	0.0004
Ti	0.038
Sn	0.001
Te	0.0048
S	49.12
SiO_2	2.20
Al_2O_3	0.52
CaO	0.073
MgO	0.56

2.3 STUDY PARTICIPANTS

The Davy McKee Corporation, Lakeland, Florida office was retained to accomplish the Pyrite Processing Study.

Davy McKee Corporation is one of the world's largest engineering and contracting organizations serving the process and metals industries which include minerals and metals, oil and gas, chemicals, petrochemicals, fertilizers, iron and steel, industrial gases, water treatment, effluent and pollution control. The Lakeland, Florida office, has major expertise in sulfuric acid, phosphoric acid and diammonium phosphate, having engineered 90% of the existing phosphate fertilizer facilities in the United States.

The Davy McKee, San Mateo, California office also a participant in the study has experience in the roasting of metal sulfides to produce sulfuric acid and the subsequent recovery of the metals contained in the raw material feed.

All the personnel involved in the study at both locations have years of experience in the areas of concern.

Davy McKee further selected specialist consulting firms for analyzing the markets and the transportation of the raw materials and the pyrite products. The selected firms are:

2.3.1 Marketing

Commodities Research Unit Ltd. (CRU) of London, UK and their affiliated representatives Consolidated Research Inc. (CRI) of New York, NY USA.

These companies as a unit have performed marketing studies for most of the major companies in the world and have outstanding credentials in their field.

2.3.2 Transportation

Jones, Bardelmeier & Co. Ltd. (JBC) an international bulk shipping consultant from Nassau, Bahamas. JBC further used the services of the Consulting Center USA Inc. of Washington, D.C. for the commodities to be handled by railroad.

Both JBC and Consulting Center USA have provided studies encompassing innovative approaches to problem solving in the marine and surface transportation industry.

2.4 STUDY TASK FORCE

A study task force was formed made up of a study manager, a market analyst, a transportation consultant and two process specialists. Each member of the task force is an expert in his field and used the collective knowledge of the task force and called on, as needed, the collective knowledge of the independent organizations to obtain the required information.

2.5 METHODOLOGY OF THE STUDY

See the Study Logic Diagram Figure 1 which shows each individual step taken to conclusion. Also see Basic Block Flow Diagram 00427.

2.5.1 Market for Pyrite Concentrate

The first thing to ascertain was whether there was a market for the Crandon pyrite in the quantity, form, and chemical analysis as it would be produced.

The preliminary market survey identified only two viable consumers that may be interested in the Crandon pyrite, but the interest was not strong enough to base a sales decision.

Copper Range has expressed a preliminary interest in Crandon pyrite. However, their total consumption would only account for about 10% of the potential production from Crandon.

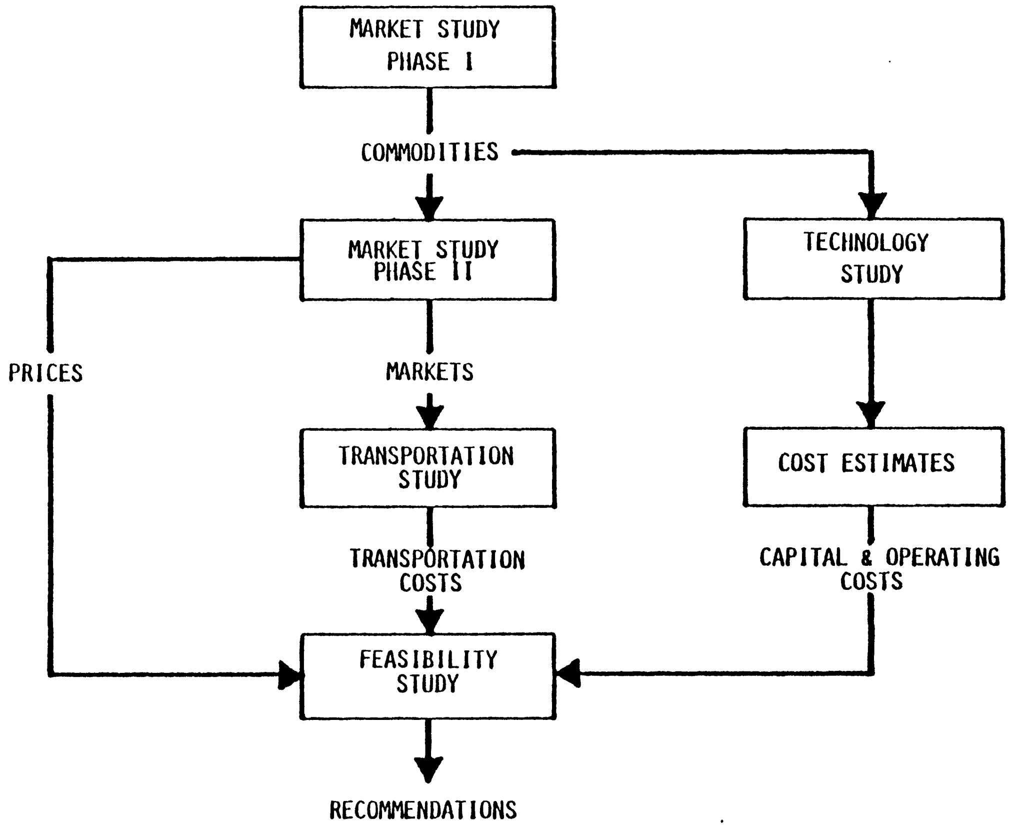
Cities Services Company (Citgo) studied the use of Crandon pyrite concentrates but concluded that they had no further interest in them. The particle size of the pyrite is too fine for their process and the transportation costs to Tennessee are too high for the use of Crandon pyrite to be feasible.

2.5.2 Pyrite Products

(See Product Logic Diagram, Figure 2.)

It was then necessary to identify other products that could be made from the Crandon pyrite concentrates.

Pyrite (FeS_2) is considered of commercial value only because of its sulfur content and is used in some countries as raw material in the manufacture of sulfuric acid. Under certain conditions and special situations elemental sulfur may also be produced.



STUDY LOGIC DIAGRAM

FIGURE 1

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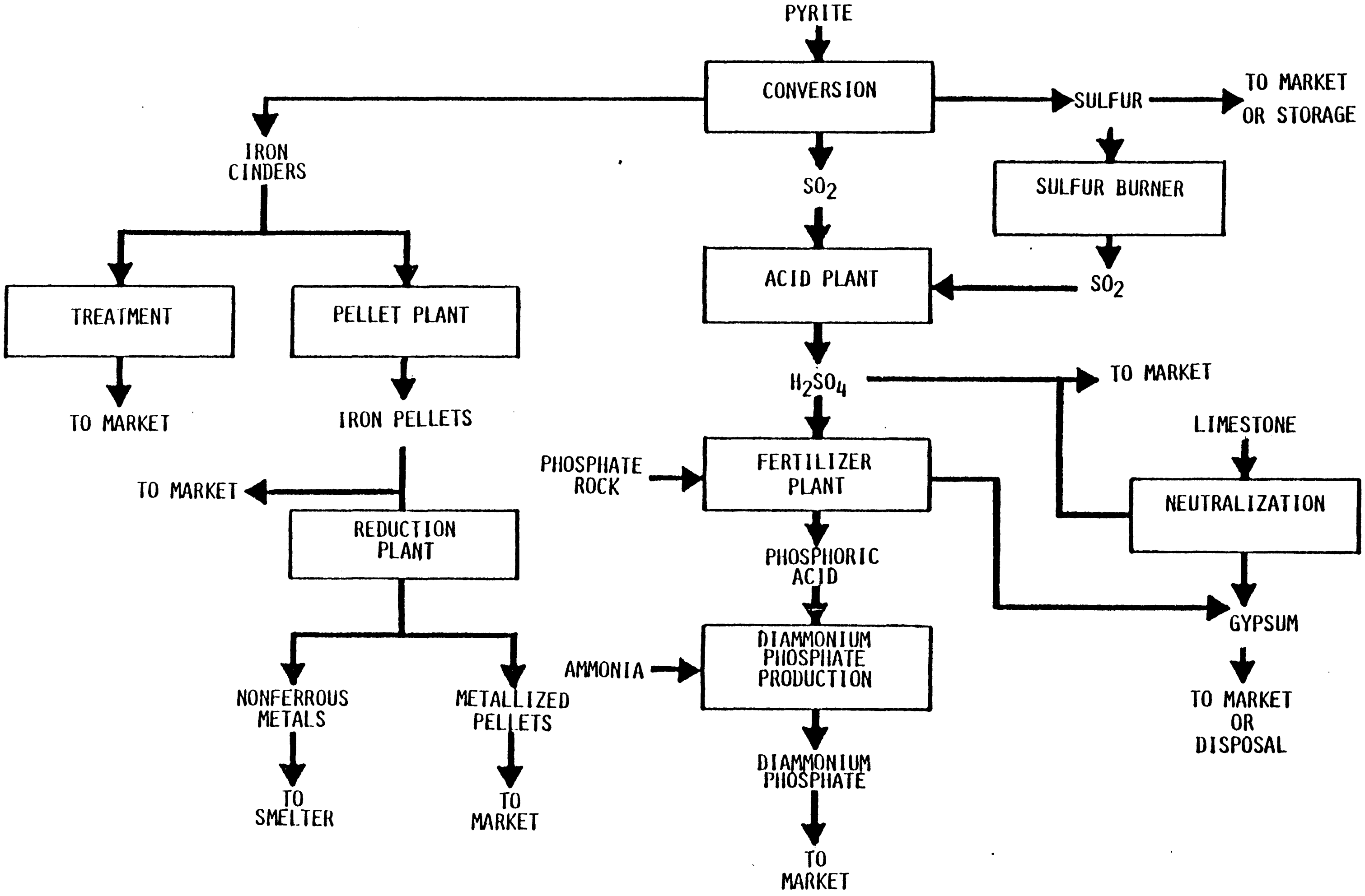
PYRITE PROCESSING STUDY



PRODUCTS LOGIC DIAGRAM

FIGURE 2

Davy McKee

EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY

Other components may play an important part in the commercial use of pyrite. The recoveries of some nonferrous components such as copper, nickel, cobalt, gold and silver, etc., may make the operation economical. Slagging components like SiO_2 and Al_2O_3 in the pyrite might also provide an iron oxide for blast furnace feedstocks. Certain impurities in the iron residues may constitute a waste disposal problem.

Using proven commercial technology, it is possible to process pyrite under one or more of the following schemes:

Pyrite (FeS_2)	to	S + FeS
	or	S + slag
	or	SO_2 + iron oxide
SO_2	to	Sulfuric Acid
Sulfuric Acid	to	Fertilizers

Some of the products that might be produced from the Crandon pyrite using the routes above are listed:

CRANDON POTENTIAL PRODUCTS

BASE CASE

Primary Products	MTPY	STPY
Pyrite (slimes)	267,400	294,500
Sulfur	134,000	147,400
H_2SO_4 (100%) - pyrite	400,000	440,000
H_2SO_4 (100%) - pyrite + zinc(1)	720,000	792,000
Iron pellets (65.2% Fe)	180,000	198,000
Liquid Sulfur Dioxide	267,400	294,500
Secondary Products		
Phosphoric acid (54% P_2O_5)	480,000	528,000
Diammonium Phosphates (18-46-0)	562,000	618,000
Gypsum	2,400,000	2,640,000
Supporting Supplies (Required)		
Phos rock (32% P_2O_5)*	810,000	891,000
Ammonia (anhydrous)*	125,000	137,000

*The above major supplies are required to produce the secondary products - phosphoric acid, diammonium phosphate and byproduct gypsum.

(1) 320,000 MTPY from the proposed zinc refinery

CRANDON POTENTIAL PRODUCTS

ALTERNATE CASE A

Primary Products

Pyrite (slimes and sands)	1,094,000 MTPY (1,203,400 STPY)
Sulfur	547,000 MTPY (601,700 STPY)
H_2SO_4 (100%) - pyrite	1,694,000 MTPY (1,863,400 STPY)
H_2SO_4 (100%) - pyrite + zinc(1)	2,014,000 MTPY (2,215,400 STPY)
Iron pellets (65.2% Fe)	718,000 MTPY (789,800 STPY)
Liquid sulfur dioxide	1,094,000 MTPY (1,203,400 STPY)

Secondary Products

Phosphoric acid (54% P_2O_5)	1,342,633 MTPY (1,476,200 STPY)
Diammonium phosphates (18-46-0)	1,572,000 MTPY (1,729,200 STPY)
Gypsum	6,713,168 MTPY (7,384,500 STPY)

Supporting Supplies (Required)

Phos rock (32% P_2O_5)*	2,268,000 MTPY (2,494,800 STPY)
Ammonia (anhydrous)*	350,000 MTPY (385,000 STPY)

*The above major supplies are required to produce the secondary products - phosphoric acid, diammonium phosphate and byproduct gypsum.

(1) 320,000 MTPY from the proposed zinc refinery

2.5.3 Product Specifications

From the product list, market specifications were prepared.

The suggested specifications for the market study are as follows:

Sulfur	99.5-99.9% pure, free from arsenic, tellurium and selenium
Sulfuric Acid	93% H_2SO_4
Iron Pellets	As per description and chemical analysis
Phosphoric acid	52% P_2O_5
Diammonium phosphate	18-46-0

Potential products to be purchased for manufacturing operations:

Phosphate rock	68-72 BPL (32% P_2O_5)
Ammonia	Anhydrous

Iron Pellets Calculated Composition

Iron Pellets			Sponge Iron 92% Reduced
Fe	-	65.1% total iron	88.75 total iron
Fe_2O_3	-	93.0	81.65 Fe met.
Cu	-	0.02	0.029
Pb	-	0.01	0.014
Zn	-	0.01	0.014
S	-	0.02	0.029
As	-	0.03	0.044
SiO_2	-	3.28	4.47
Al_2O_5	-	0.78	1.06
CaO	-	1.47	2.00
MgO	-	0.83	1.13
Mn	-	0.3	0.41
O_2	-	-	2.05
Au	-	0.05 gr/T	
Ag	-	4.0 gr/T	

These pellets should have an average diameter of 12mm, with a compressive strength of +400 kg/pellet.

TABLE V

SMELTER SULFURIC ACID SPECIFICATIONS

93% H_2SO_4 (-66 Baume)

H_2SO_4	93 - 94
SO_2	300 - 500 ppm
Iron	30 - 50 ppm
NO_3	Less than 1 ppm
Cadmium	.01 - .03 ppm
Mercury	1 ppm
Zinc	1 ppm
Lead	1 ppm
Arsenic	Less than 1 ppm
Chlorine	Less than 0.5 ppm
Copper	Less than 1 ppm
Selenium	Less than 1 ppm
Color	Water white to light yellow

TABLE VI

2.5.4 Market Analysis of Selected Products & Raw Materials

The market analysis of the selected products indicated a limited market potential for liquid sulfur dioxide and gypsum and these were dropped from further investigation as to capital and operating costs.

Process centers were selected for the purpose of this study to investigate the effect of transportation costs on the overall economics. The centers chosen were:

Green Bay Wisconsin
Evansville Indiana

Selection of these locations was soley for the purpose of estimating transportation costs and does not imply any intention on the part of Exxon to utilize these locations for any purpose.

The market analysis also indicated the major marketing areas for the final products, depending on the location of the individual process centers. For the Green Bay process center the marketing area was Chicago, Illinois for all products except diammonium phosphate (DAP) which is Fort Madison, Iowa. For the Evansville, Indiana process center, the marketing area was St. Louis, Missouri except for diammonium phosphate (DAP) which, again, was Fort Madison, Iowa.

The market analysis of the raw materials, phosphate rock and anhydrous ammonia indicated adequate supply. Therefore, the raw materials and the remaining product would be studied further for transportation modes and costs.

2.5.5 Transportation

The purpose of the transportation report is to provide the rates and methods of transportation and intermodal handling for the commodities to be produced and selected, for further consideration in the study.

2.5.6 Process Technology

The market analysis determined the commodities to be produced from the Crandon pyrite. While the transportation study was in progress, the process engineers were reviewing the technology available for producing the selected marketable products. The processes were then evaluated as to their commercial viability, impact in the environment, capital and operating costs and, if not already in commercial use, the possible future potential.

As the process engineers selected the possible technologies to be used, block flow diagrams were prepared and process flowsheets made for those processes with the most potential.

2.5.7 Capital & Operating Costs

Capital costs were then prepared for the selected commercial processes. With those costs in hand and the criteria formulated for the operating cost the operating cost for the products were calculated.

2.5.8 Revenues

The revenues to be received from each product via the various process routes were determined during the market study. These are now used along with the transportation costs and the operating costs to determine the feasibility of each product route.

3. MARKETING

3.1 INTRODUCTION

This part of the Pyrite Processing Study covers the marketing of the Crandon pyrite concentrates and the products resulting from the treatment of these materials. It also includes the marketing of the sulfuric acid that may be generated in a proposed zinc refinery treating Crandon zinc sulfide concentrates.

Commodities Reseach Unit (CRU) and their U.S. affiliation, Consolidated Research Inc. (CRI) were selected to perform the market study and the analysis of the products from the Crandon pyrite that can be marketed. A copy of CRU's complete report is available in the Appendix for further review. Both products to be marketed or purchased to make the final products have been considered. The various products and materials that were examined are as follows:

Products to be Marketed

Pyrite concentrates
Liquid SO_2
Sulfuric Acid
Sulfur
Iron Pellets
Phosphoric Acid
Diammonium Phosphate
Gypsum

Products to be Purchased

Phosphate rock
Ammonia

The opportunities in the U.S./Canadian market based on the source of the products have been investigated and assessed.

Products Considered But Not Cost Estimated

During the early phase of the CRU Marketing Study it was determined that the market for liquid SO_2 was not large enough (200,000 MTPY) in the process center areas to warrant estimating of the capital and operating costs for liquid SO_2 production.

The U.S. market for byproduct gypsum is 600,000 metric tons per year against the Exxon potential production of 2.4 million MTPY. The gypsum produced in the manufacture of phosphoric acid contains impurities that are not usable in gypsum board and other products used in the building trades without additional treatment, therefore the operating and capital costs were not further investigated.

Further, it was realized that the market per sé for phosphoric acid was a captive market and that the major portion of the market was used in the production of fertilizer. Therefore, the production cost of the phosphoric acid was included in the diammonium phosphate capital and operating costs.

The market study indicates that the demand for elemental sulfur is strong, and it has been recommended that the process for producing elemental sulfur be investigated. During the analysis of the commercial processes for making elemental sulfur, it was found to be energy intensive and it is doubtful that it can compete economically with Frasch sulfur or other sulfur recovery processes.

Also eliminated from further investigation were the iron products from pyrite such as pigments, iron powder, etc., either due to a limited market or production cost considerations.

3.2 MARKETS FOR PYRITE CONCENTRATES

Pyrite once was the world's major source of sulfur, but its relative importance has declined in this century because of the development of the Frasch process for mining elemental sulfur, and perhaps more importantly because of production of byproduct sulfur and sulfuric acid from nonferrous metal smelters, natural gas and petroleum.

Nevertheless, in Europe and Asia pyrite is still a significant source of sulfur. The USBM estimated that in 1975, of the total world sulfur production of almost 50 million tons, pyrite accounted for 10.2 million tons. The major processors of pyrite are the USSR, Spain, China, Japan and Italy. These countries have plentiful local sources of pyrite and there is no chance that it would be economical to ship pyrite to them from the U.S.

With a few exceptions, the pyrite roasting industry in North America has disappeared because of competition from less expensive sulfur sources. Moreover, industry experts are convinced that there is little chance of a reversal because of (a) almost no existing roasting facilities, (b) the high cost of pyrite roasting, (c) future adequacy in North America of byproduct sulfur/sulfuric acid supplies from coal burning power plants, etc.

North American Producers

Pyrite occurs very commonly in mineral deposits with sulfide mineralization, and several North American mines separate waste pyrite from their ores. In almost all cases they have no use for this material and store it in tailings ponds or use it as mine fill. Table 1 shows the amount of pyrite that has been processed in the U.S. since 1950.

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In the United States, only one company today processes the pyrite it mines. This is Cities Service at its copper/zinc/pyrite mines at Copperhill, Tennessee. Copperhill is a very old and unusual operation, whose economics have depended as much on the output of byproducts as on copper. Besides roughly 10,000 STPY of 52% zinc concentrates, the major byproducts have been sulfuric acid and iron oxide pellets derived from processing pyrites.

The iron circuit at Copperhill apparently never performed well and was shut down in May 1979. Currently, Copperhill still roasts 3,000 STPD (approximately one million STPY) of pyrite solely for production of sulfuric acid, and virtually all the iron cinder is stored.

Small quantities of byproduct pyrite are sold from two other U.S. mines to small distributors who in turn dry and size the material for sale to several very small markets. The Climax (Colorado) mine of Climax Molybdenum Co. (AMAX) sells about 3,000 STPY in this way, reportedly for $22/ton F.O.B. Climax, wet.

TABLE 1

U.S. PRODUCTION OF Pyrite(1)

Year	1000 tons
1950	946
1955	1,023
1960	1,032
1965	889
1970	859
1975	635
1977	420e

Note

(1) Pyrite that was processed
e CRU estimate based on reported sulfur content of pyrite.

Source: USBM

In Arizona, Magma Copper Co. (Newmont) similarly sells about 7,000 STPY. In both cases the amount of pyrite sold is only a small fraction of the amount available at these mines. The main markets for this pyrite are the acidification of soil (especially in California and other parts of the Southwest where soils are basic) and for coloring of bottle glass.

Based on CRU interviews, they estimate that the U.S. market for pyrite in soil acidification is under 10,000 STPY, and for bottle glass is under 5,000 STPY. In any event, neither of these markets is available for Exxon's pyrite; soil acidification, because of the shipping distance to areas where it is needed; and beer bottle glass, because the pyrite must be +20 mesh so that it will not blow out the stacks of the glass making furnaces.

In Canada, roasting of pyrite is limited to several long existing facilities. Inco, at Copper Cliff, Ontario, actually roasts a nickel bearing pyrrhotite, with recovery of the nickel as the main motivation for the process. Approximately 800,000 STPY of pyrrhotite containing over 1% Ni is processed to make 5.3 million kg of nickel oxide, 630,000 tons of iron oxide pellets, and sulfuric acid (actually produced by Canadian Industries, Ltd. (C-I-L Inc.) in an adjacent facility).

Cominco, at Kimberly, B.C., roasts 250,000-300,000 STPY of pyrite and/or pyrrhotite from local mines to make sulfuric acid which is used in phosphate fertilizer production. The remaining iron calcine is stockpiled.

The only other significant movement of pyrite in Canada is from Noranda, which ships about 23,000 STPY from the tailings pile of the former Horne Mine (shut down July 1976) at Noranda, Quebec. This material is sent to the White Pine Copper Smelter (Copper Range Co.) in Michigan at a price of $1/ton plus freight (approximately $20/ton). White Pine, which mines a low sulfide ore, is in the unusual position of having a deficiency of sulfur for its smelting process; thus the purchase of pyrite.

Markets For Exxon's Pyrite

As no other company is likely to build a new pyrite roasting facility to use Exxon's concentrates, the only possible customers are companies within shipping range that already use pyrite in existing facilities. This narrows the list quickly to two prospects: White Pine, Michigan and Copperhill, Tennessee, both of whom were contacted.

White Pine has an obvious interest in Exxon's pyrite because Crandon is closer than Noranda, Quebec, and therefore the delivered cost might be less. Unfortunately, White Pine's total requirements represent less than 10% of Exxon's projected output of pyrite concentrates.

The White Pine specifications of impurities contained in the Noranda pyrite are as follows:

Zn	2%
Pb	3%
As	1%
Ni	250 ppm
Bi	100 ppm
Se	100 ppm

White Pine was concerned about their ability to handle Exxon's extremely fine material and about the dust control problems that could result.

Cities Service Company, at Copperhill, Tennessee is the only consumer of pyrite that would be capable of using all of Crandon's pyrite concentrate production. Exxon approached Cities Service Company to determine the extent of interest that Citgo might have in Crandon's pyrite production. After further investigation by both companies as to the nature of the pyrite material and the freight rates, Cities Service Company notified Exxon that they were no longer interested in the Crandon material.

3.3 PRODUCTION TO ELEMENTAL SULFUR

Market for Sulfur

Sulfur is one of industry's most important and versatile raw materials. It finds application at some stage in nearly all industrial production, usually in the form of sulfuric acid. Sulfur mainly occurs in the elemental form, metallic sulfides, sulfate minerals, in conjunction with liquid and gaseous hydrocarbons, and most abundantly in coal.

In the western world, the major producer is North America, which in 1978 produced 19.2 million metric tons, equivalent to 35% of the global output. West Europe was the second major western world producer whose output totalled 7.7 million metric tons in 1978.

The western world remains the major consumer; accounting for almost 71% of the consumption, reaching a record level of 36.3 million metric tons of sulfur in 1978.

As in the case of production, North America accounts for the major share of the consumption. North America sulfur consumption reached record levels of 14.7 million metric tons. Similarly, West European consumption recorded new highs of almost 11 million metric tons.

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PYRITE PROCESSING STUDY
SUMMARY

Current Situtation and Outlook

Demand for sulfur continued its upward trend, due principally to the growth in the phosphate fertilizer industry. However, there was no matching growth in supply, and by mid year delivery schedules were falling behind, as the market tightened in the second half of 1978.

Output from nonelemental sectors rose due largely to a recovery in the nonferrous metals smelting sector. Given the improved market conditions, pyrite production increased by 2%. Output of elemental sulfur remained unchanged as the increased production by recovered producers was cancelled out by the declining Frasch production in the U.S. and Mexico. The sulfur market entered into a period of growing demand and tightening supply, which eventually manifested itself in higher prices. By the end of 1978 prices were renegotiated by +$10 per ton. This situation has improved little in 1979. Looking ahead, western world demand will increase as a result of the continuing growth of the fertilizer industry's requirements, particularly phosphoric acid and the more modest growth in industrial end uses. It is evident that the western world supply/demand balance will be tight until the 1980s unless sulfur resources are developed, which by today's standards are considered uneconomic.

Unfortunately, there has been no historical precedent for a sulfur shortage of the potential dimensions identified. Until recently, there have always been reserves of material available to voluntary producers when market developments have outstripped byproduct sulfur supply. Thus it must be assumed that unless supplies of abatement sulfur or sulfur recovered from coal, oil shales, etc., enter the market, the growth in demand will slow down in all sectors as investment in sulfur using capacity slows, awaiting assurances of supply of sulfur at realistic prices. There are no structural changes in the pattern of demand anticipated, merely a deceleration in growth in response to market prices until new sources can be exploited.

The United States Sulfur Industry

The United States sulfur industry is the world's major producer. In 1978, domestic production of 11,168,000 metric tons of sulfur represented 20% of global production. While consumption of 12.6 million metric tons accounted for 23% of world usage. Currently the Frasch sulfur sector accounts for the major output of sulfur, but as can be seen from the following Table 2, Frasch usage has fallen steadily over the past 5 years, following a modest recovery in the early 1960s from its downward trend. The figure clearly illustrates how the increased production over the past 2 years has stemmed entirely from the output of recovered elemental sulfur and byproduct sulfuric acid.

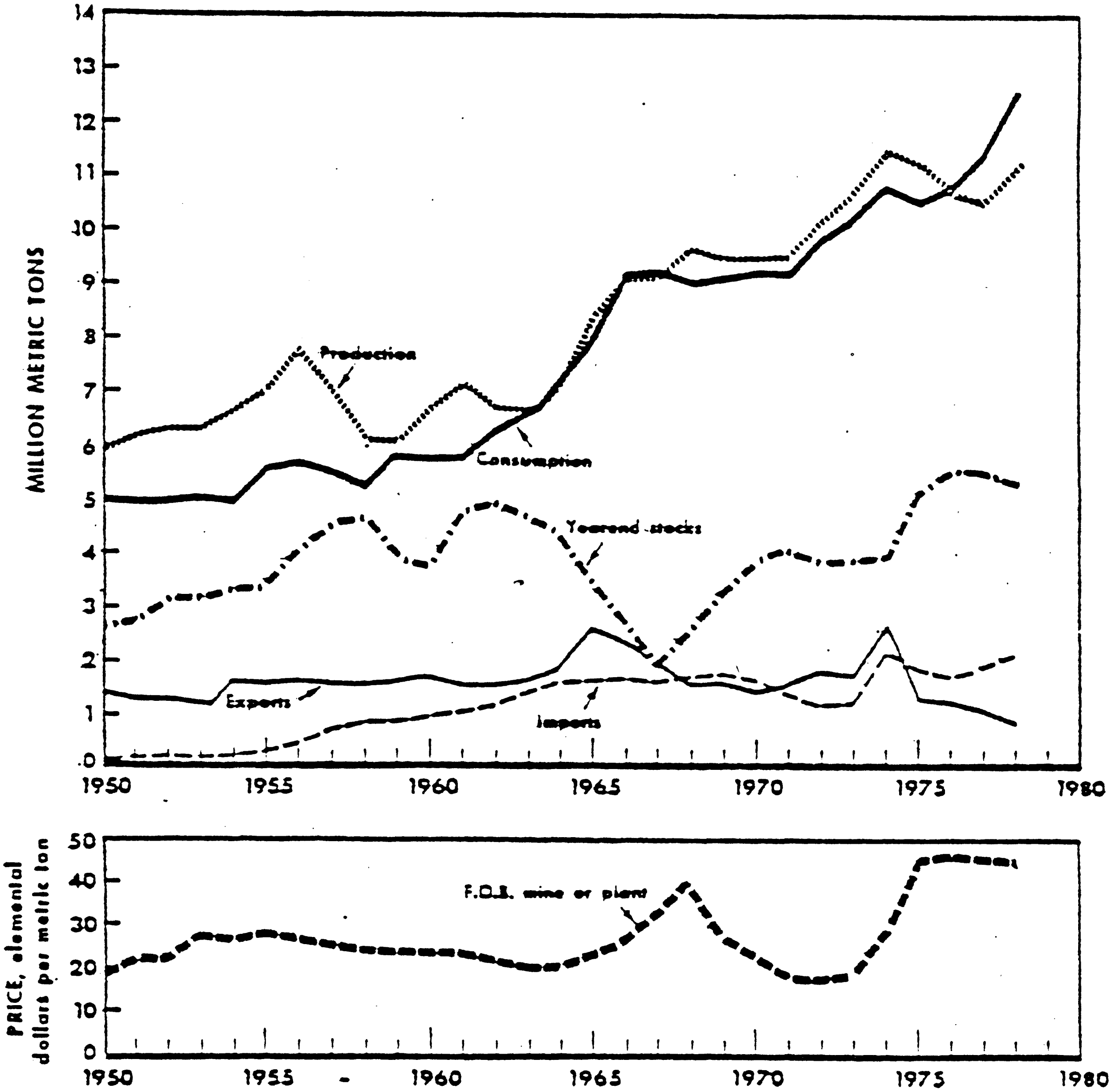

Figure 1

Trends in the Sulfur Industry in the United States

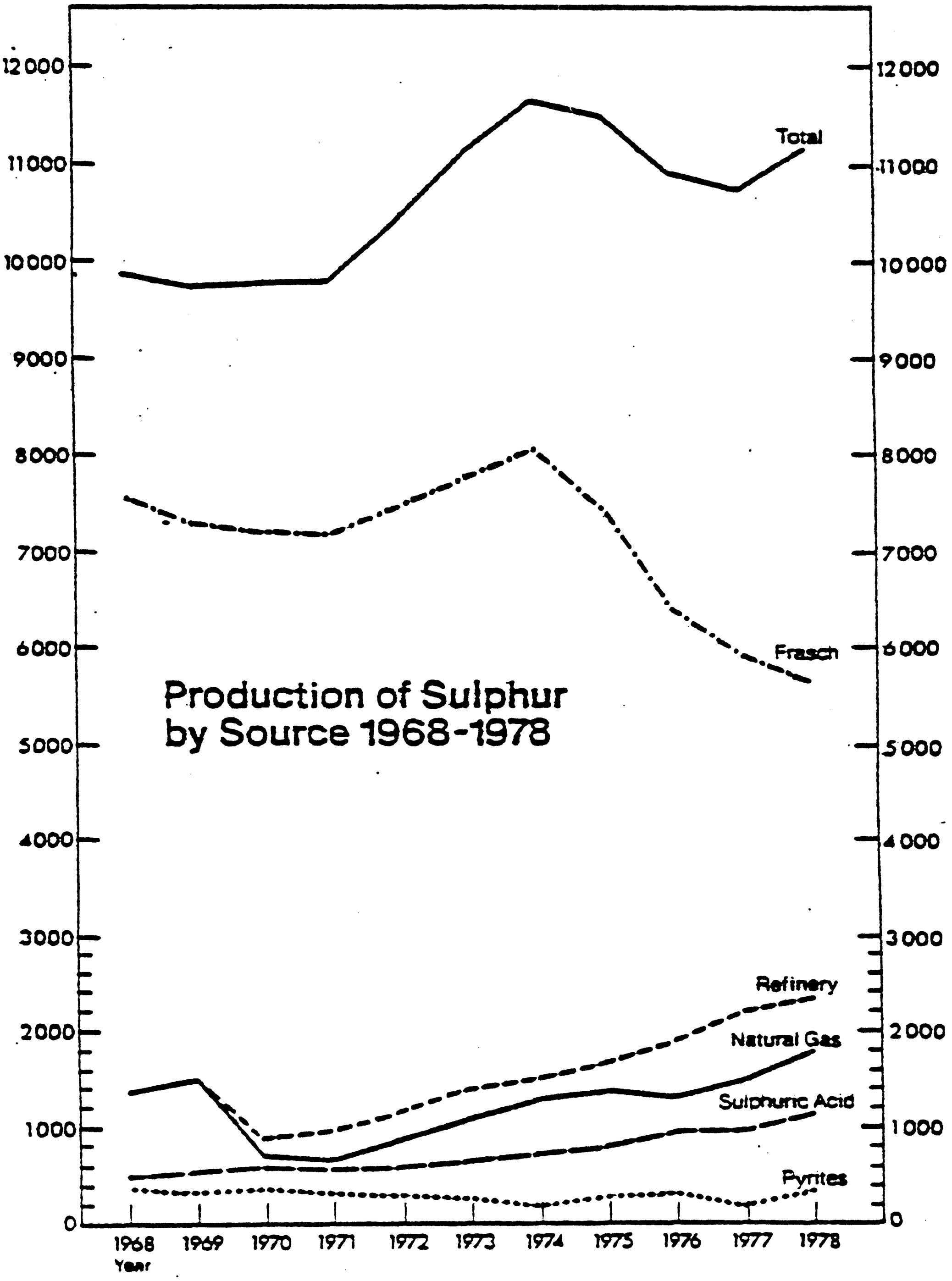
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Total
Frasch
Production of Sulphur
by Source 1968-1978
Refinery
Natural Gas
Sulphuric Acid
Pyrites
1968
Year
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978

Figure 2

While production of sulfur has fluctuated considerably over the past 10 years, the fluctuations in the consumption of sulfur have been far less pronounced with the trend moving upward. The United States remains a net importer of sulfur. In 7 out of the past 10 years, imports have exceeded exports, including the last 4 consecutive years. Mexican Frasch and Canadian recovered sulfur producers have played an increasing role in the U.S. market where their combined exports to the U.S. totaled 1,967,000 metric tons in 1978.

The developments of the United States industry over the past 25 years is summarized in Figure 2.

U.S. Current and Projected Supply

U.S. production of sulfur in all forms totaled 11,168,000 metric tons in 1978, a 4% increase over the previous year.

Table 2 - Production of Sulfur in all Forms
(1000 metric tons)

	1966	1970	1976	1977	1978
TOTAL	9,891	9,710	10,879	10,727	11,168
Frasch	7,579	7,196	6,365	5,915	5,648
Recovered					
(1) Natural gas	1,381	669	1,298	1,426	1,752
(2) Refinery		811	1,890	2,198	2,303
Byproduct H_2SO_4**	437	546	957	960	1,103
Pyrite	368	344	291	169	301
Other forms[2]	126	114	78	59	61

Sources:
1. Includes a small quantity from coking operations
2. Hydrogen sulfide and liquid sulfur dioxide

** Further analysis of the byproduct sulfuric acid is included in Section 2.3.

Production of Frasch sulfur has declined from its peak of over 8 million metric tons in 1974, to its present level of 5,648,000 metric tons. The decline in production over the past 4 years has resulted from an interaction of the following factors:

(1) The closure of a number of mines with diminishing reserves, particularly on the Gulf Coast. During the past 3 years, 5 Frasch mines have ceased production - Lake Pelto and Grande Ecaille operated by Freeport Minerals Co. and Spindletop, Fannett and Bully Camp operated by Texasgulf. Commissioning of the Comanche Creek mine by Texasgulf has been insufficient to redress the balance.

(2) The increased natural gas prices, a vital element in the production of Frasch sulfur.

A brief discussion of the cost structure of the industry will clearly illustrate why there is little chance of any expansion of the Frasch industry unless a significant technical break-through is achieved in energy saving. Of the costs of production, the cost of natural gas is crucial, and it is significant that many of the mines are fortunate to have contracts for long term supplies of gas. For example, Freeport's Garden Island Bay dome gas supply is assured until 1989 through an intrastate contract, while Grand Isle supplies are contracted for 10 years with an intrastate gas company. This has insured that gas supplies are available below $2 per mcf. The availability of gas at these prices is crucial to the older mines, where the water requirement has been increasing.

An indication of the future for those companies still in production can be gauged from the following estimates of gas consumption per operation.

Location	Gas Consumption mcf/ton
Louisiana	
Garden Island Bay	6.9
Grand Isle	3.8
Texas	
Comanche Creek	41.5
Long Point	9.1
Moss Bluff	9.0
New Gulf	7.6
Rustler Springs	5.0

During the review period all of the above mines will see their consumption of gas per metric ton of sulfur increase as the mines age.

Recovered Elemental Sulfur

Production of recovered sulfur reached record levels of 4,055,000 metric tons in 1978, a 12% increase on the previous year. As a result of the decline in Frasch production, recovered sulfur accounted for 36% of total domestic sulfur production.

Table 3 - Recovered Elemental Production*
(1000 metric tons)

	1970	1975	1976	1977	1978
Total recovered	1,480	3,017	3,188	3,624	4,055
Natural gas	669	1,364	1,298	1,426	1,752
Petroleum refinery	811	1,653	1,890	2,198	2,303
Year end stocks		273	270	269	222

*Mineral Industry Survey

Unlike the Frasch industry, which is characterized by a small number of producers and mines located in the States, the recovered sulfur industry is highly fragmented. In 1978 recovered sulfur was produced by 57 companies, operating 147 plants in 29 states. However, the majority of the operations are small scale and five major companies operating 37 plants accounted for 56% of total recovered sulfur production in 1978.

Recovered Elemental Sulfur - Natural Gas

In 1979, possibly more so than ever before, the forecast of recovered sulfur production from natural gas sources is dependent on political decisions.

Recovered Elemental Sulfur - Other Forms

Recovered sulfur, other than from natural gas processing or petroleum refineries is at the moment minimal. However, while operations in this area may be of only minor significance now, they are considered by certain sources to be areas of major potential.

These unconventional sources of recovered sulfur can be categorized as follows:

(1) Coal gasification
(2) Oil shales and tar sands
(3) Power plants

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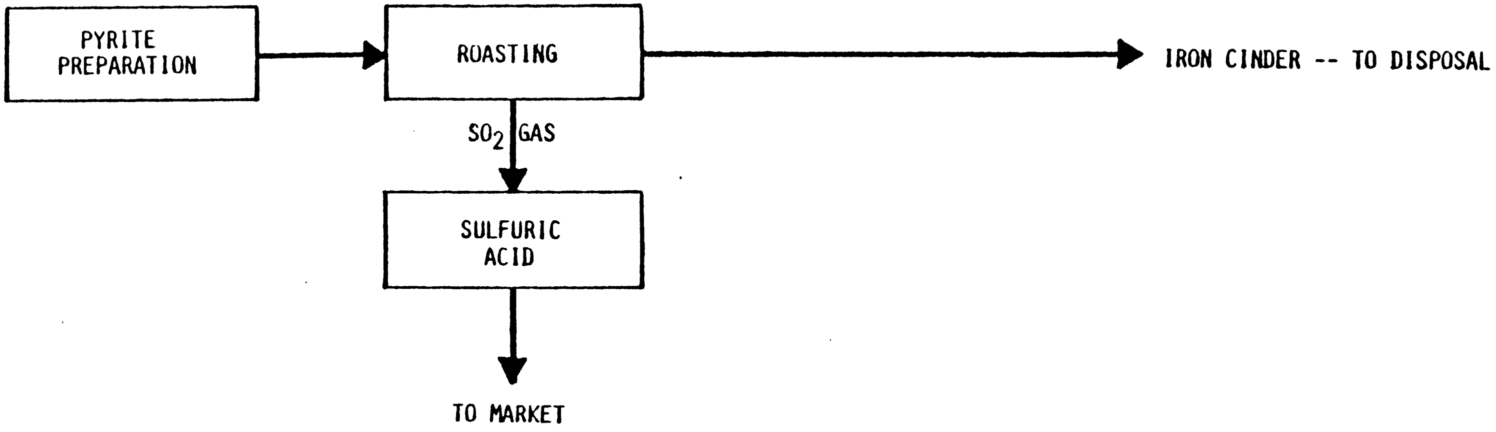
(1) Coal gasification - given the impetus provided by the recent energy policy to produce 1-1.5 million barrels per day of synthetic fuel from coal liquification and gasification by 1990 a substantial quantity of sulfur could be recovered. The recovery of the sulfur at the point of production would also enhance the chances of production resulting from the economies in pollution control. At the moment, however, there are no commercial operations in production, but tests are underway on both pilot and semi-industrial scale plants. It is considered unlikely that any commercial production will be seen before 1990 in view of the cost element. Two pilot plants to produce synthetic fuel will cost over $3.5 billion, while the fuel itself is forecast to cost between $27-47 per barrel.

(2) Oil shales and tar sands - would appear to suffer from the same disadvantages as coal gasification, notably technological and financial. In the U.S., the largest deposits of oil shales are located on the borders of Utah, Colorado and Wyoming. Government proposals are to produce 0.5 million barrels per day of fuel. The U.S. oil shales are generally thought to have a fairly low sulfur content and cannot be regarded as a major source of recovered sulfur. Sulfur recovery from oil shales is not expected before 1990, and is forecast to be in the order of 200,000 STPY.

(3) Power plants - As a result of burning high sulfur coal, have caused SO_2 emissions which, until recently, have not been recovered. However, under pressure from the Environmental Protection Agency (EPA), power stations are obliged to comply with clean air regulations. The question of the form in which the SO_2 emissions are recovered remains. A recent publication** by the Tennessee Valley Authority and EPA has studied the relative trends of the processes for cleaning up the SO_2 emissions. The conclusion is that recovery of elemental sulfur (by the Wellman-Lord/Allied process) was in excess of the recovery by conventional sulfuric acid production, even when the increased cost of distributing sulfuric acid was considered. Elemental sulfur is recovered from two utility companies, North Indiana Public Service Co. (NIPSCO) at Mitchell Station which currently recovers 60 STPD sulfur and Public Service Co. of New Mexico which produces 40 STPD sulfur. Annual production from these two units is estimated to be 35,000 ST of sulfur.

* Sulfur, Mineral Policy Series, Dept. of Energy, Minerals & Resources, Canada

** "Potential Abatement Production and Marketing of Byproduct Sulfuric acid in the U.S." prepared for the U.S. Environmental Protection Agency, Washington DC.



ALR 1/15/80

PROCESS BLOCK FLOW DIAGRAM

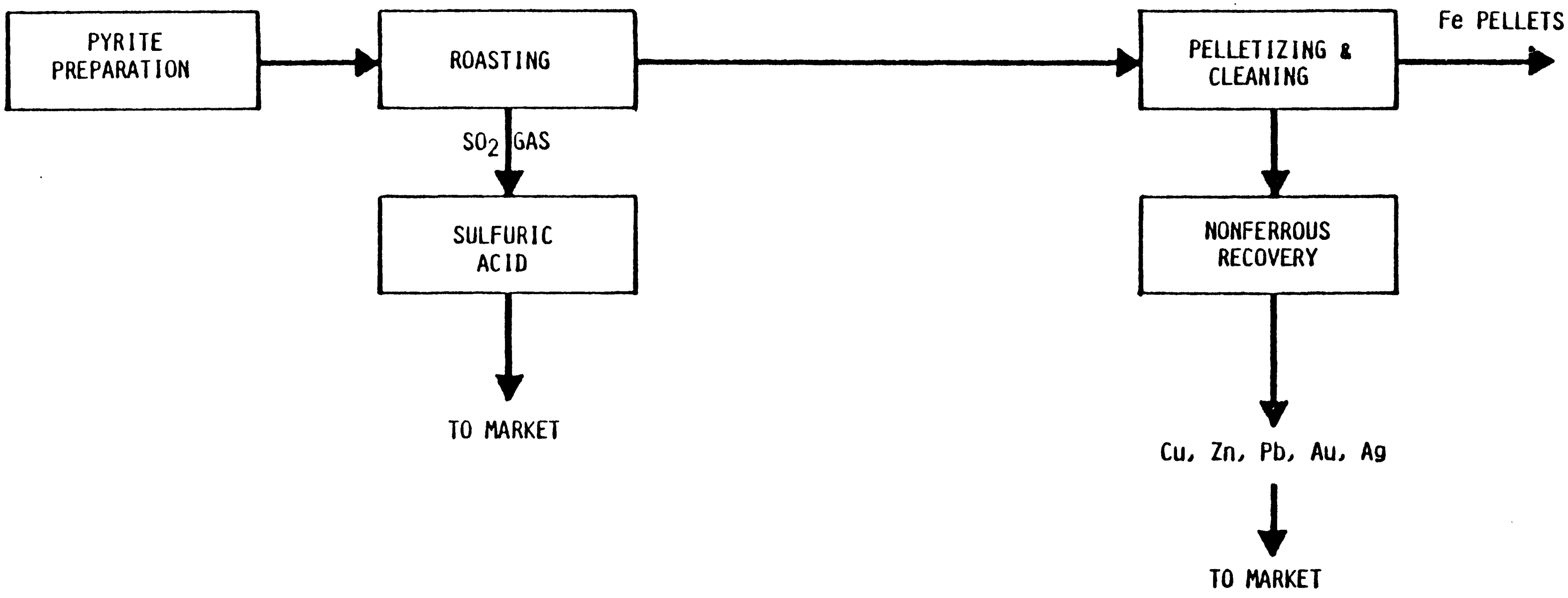
SULFURIC ACID ONLY. IRON CINDER TO DISPOSAL

FIGURE 1

Davy McKee

EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY



PROCESS BLOCK FLOW DIAGRAM

SULFURIC ACID, IRON PELLETS
AND NONFERROUS METAL RECOVERY

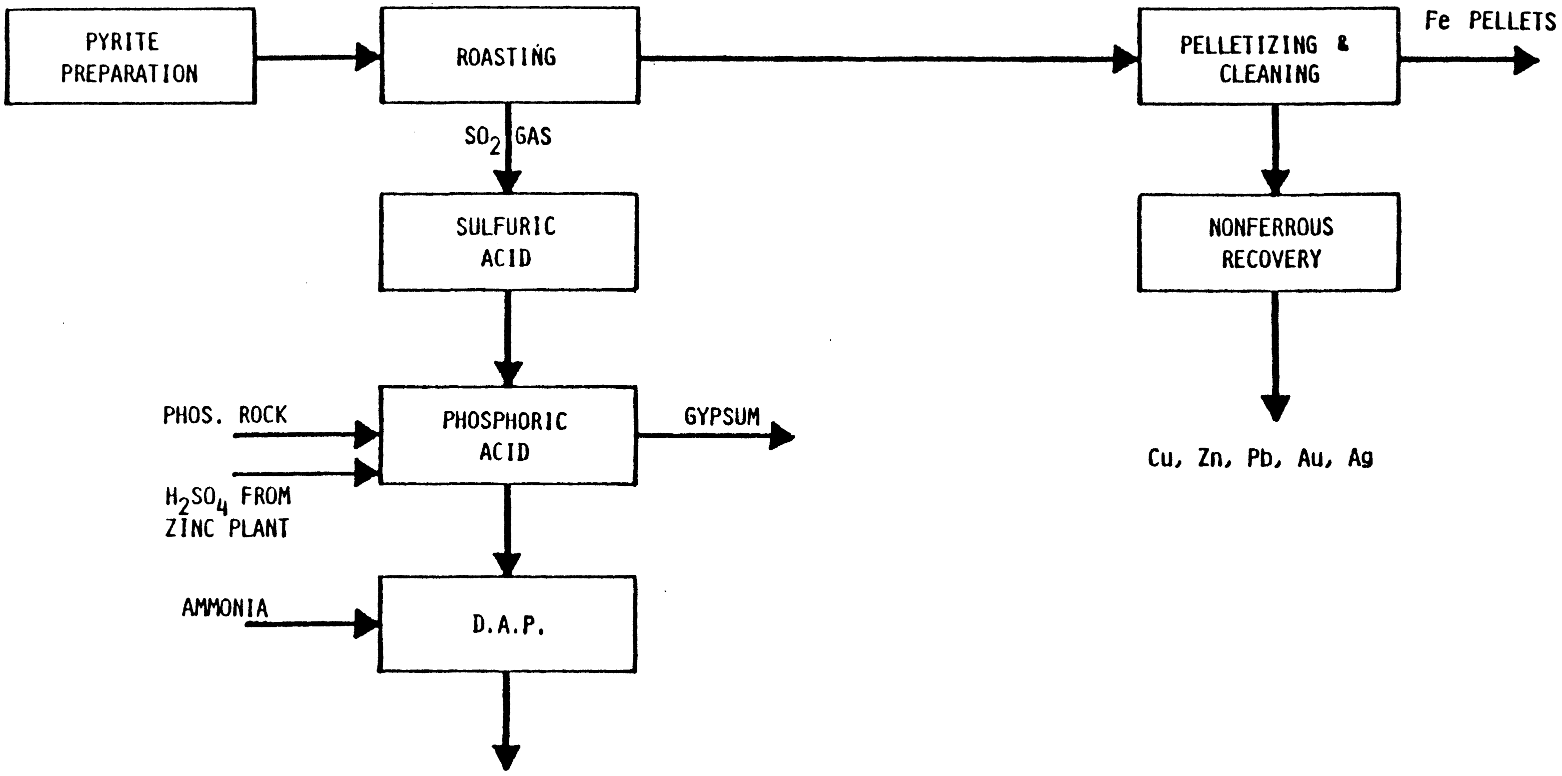
FIGURE 2

ALR 1/15/80

Davy McKee

EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY



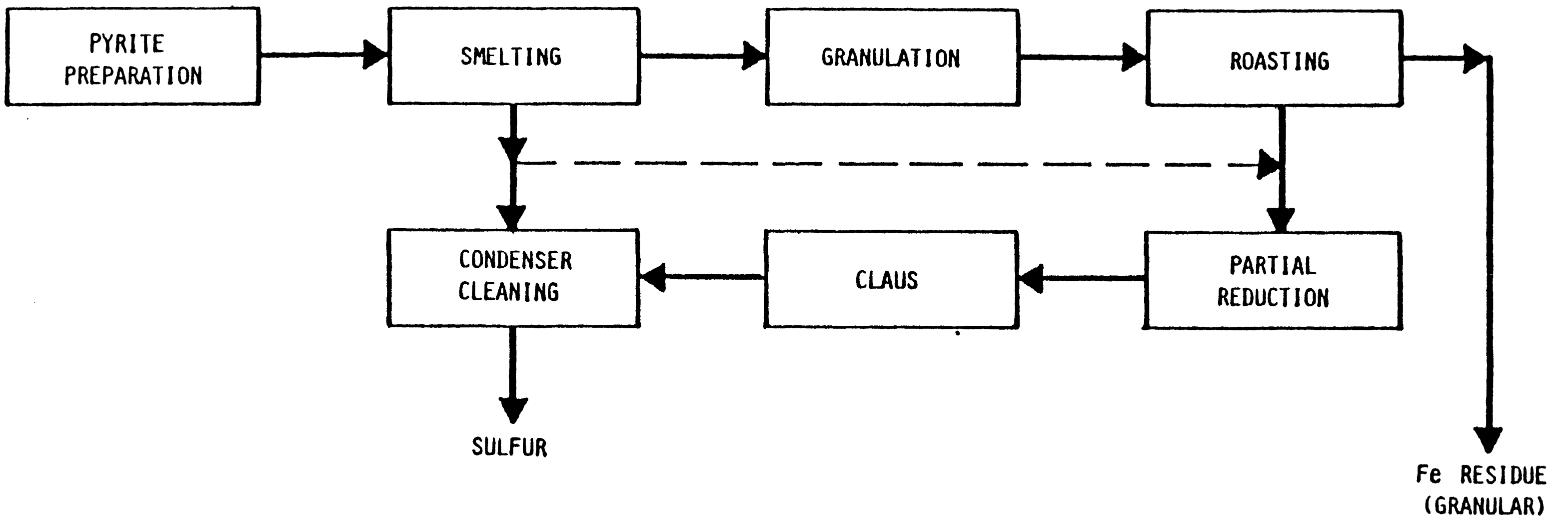
PROCESS BLOCK FLOW DIAGRAM
PELLET ROUTE
SULFURIC ACID, PHOSPHORIC ACID, D.A.P. AND IRON PELLETS
FIGURE # 3

ALR 1/15/80

Davy McKee

EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY



PROCESS BLOCK FLOW DIAGRAM
SULFUR RECOVERY & IRON RESIDUE

FIGURE # 4

ALR 1/15/80

Davy McKee

EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY

PYRITE PROCESSING STUDY

CAPITAL COST ESTIMATES

Sulfuric Acid Only - Pyrite Cinders to Waste (Figure 1)

	Base Case		Alternate Case A	
	267,400 MTPY Pyrite Feed		1,094,000 MTPY Pyrite Feed	
	Capacity	$ Cost Millions	Capacity	$ Cost Millions
Pyrite Handling (01)	267,400 MTPY	4.0	1,094,000 MTPY	10.0
Pyrite Roasting Plant (02)	267,400 MTPY	21.5	1,094,000 MTPY	69.0
Sulfuric Acid Plant (03)	400,000 MTPY	18.0	1,694,000 MTPY	68.0
Offsites		20.5		63.0
TOTAL		64.0		210.0

Figure 5

PYRITE PROCESSING STUDY

CAPITAL COST ESTIMATES

Sulfuric Acid, Iron Pellets, Nonferrous Metals Reclamation (Figure 2)

	Base Case		Alternate Case A	
	267,400 MTPY Pyrite Feed		1,094,000 MTPY Pyrite Feed	
	±25% Accuracy		Order of Magnitude Accuracy	
	Capacity	$ Cost Millions	Capacity	$ Cost Millions
Pyrite Handling (01)	267,400 MTPY	4.0	1,094,000 MTPY	10.0
Pyrite Roasting Plant (02)	167,400 MTPY	21.5	1,094,000 MTPY	69.0
Sulfuric Acid Plant (03)	400,000 MTPY	18.0	1,694,000 MTPY	68.0
Iron Pellet Plant (06)	180,000 MTPY	11.4	718,000 MTPY	25.0
Nonferrous Reclamation (07)		1.6		4.0
Offsites		27.5		74.0
TOTAL		84.0		250.0

Figure 6

PYRITE PROCESSING STUDY

CAPITAL COST ESTIMATES

DAP, Sulfuric Acid, Iron Pellets, Nonferrous Metals Reclamation (Figure 3)

	Base Case		Alternate Case A	
	±25% Accuracy		Order of Magnitude Accuracy	
	Capacity	$ Cost Millions	Capacity	$ Cost Millions
Pyrite Handling (01)	267,400 MTPY	4.0	1,094,000 MTPY	10.0
Pyrite Roasting (02)	267,400 MTPY	21.5	1,094,000 MTPY	69.0
Sulfuric Acid Plant (03)	400,000 MTPY	18.0	1,694,000 MTPY	68.0
Phosphoric Acid-Diammonium Phosphate (04) and (05)	562,000 MTPY	45.5	1,572,000 MTPY	120.0
Iron Pellet Plant (06)	180,000 MTPY	11.4	718,000 MTPY	25.0
Nonferrous Metal Reclamation (07)		1.6		4.0
Offsites		43.0		104.0
TOTAL		145.0		400.0

Figure 7

PYRITE PROCESSING STUDY

CAPITAL COST ESTIMATES

DAP, Sulfuric Acid, Iron Pellets, Nonferrous Metals Reclamation (Figure 3)

No Zinc Refinery Sulfuric Acid

	Alternate Case B		Alternate Case B-1	
	Capacity	$ Cost Millions	Capacity	$ Cost Millions
Pyrite Handling (01)	267,400 MTPY	4.0	1,094,000 MTPY	10.0
Pyrite Roasting (02)	267,400 MTPY	21.5	1,094,000 MTPY	69.0
Sulfuric Acid Plant (03)	400,000 MTPY	18.0	1,694,000 MTPY	68.0
Phosphoric Acid-Diammonium Phosphate (04) and (05)	313,000 MTPY	33.5	1,322,228 MTPY	112.0
Iron Pellet Plant (06)	180,000 MTPY	11.4	718,000 MTPY	25.0
Nonferrous Metal Reclamation (07)		1.6		4.0
Offsites		43.0		104.0
TOTAL		133.0		392.0

Figure 8

PYRITE PROCESSING STUDY

UNIT PRODUCT VALUES

		Operating Costs/MT			
		Green Bay		Evansville	
Product	Market Price/MT	Base Case	Alternate Case A	Base Case	Alternate Case A
Sulfuric Acid	15.00	40.04	31.78	50.25	41.62
Iron Pellets	42.00	41.97	26.79	41.97	26.79
Credit for Nonferrous Metals		-20.55	-21.11	-20.55	-21.11
		21.42	5.68	21.42	5.68
Diammonium Phosphate	220.00	165.10	159.12	166.71	164.12

Base Case - 267,400 MTPY Crandon Pyrite
Alternate Case A - 1,094,800 MTPY Crandon Pyrite
Diammonium Phosphate - includes 320,000 MTPY of sulfuric acid from zinc refinery

Figure 9

PYRITE PROCESSING STUDY

UNIT PRODUCT VALUES

		Operating Costs/MT			
		Green Bay		Evansville	
Product	Market Price/MT	Alternate Case B	Alternate Case B-1	Alternate Case B	Alternate Case B-1
Sulfuric Acid	15.00	40.04	31.78	50.25	41.62
Iron Pellets	42.00	41.97	26.79	41.97	26.79
Credit for Nonferrous Metals		-20.55	-21.11	-20.55	-21.11
		21.42	5.68	21.42	5.68
Diammonium Phosphate	220.00	183.05	165.15	191.21	172.20

Base Case - 267,400 MTPY Crandon Pyrite (400,000 MTPY sulfuric acid)
Alternate Case A - 1,094,800 MTPY Crandon Pyrite (1,694,000 MTPY sulfuric acid)
Diammonium Phosphate - no sulfuric acid from zinc refinery

Figure 10

PRODUCT ROUTE

Sulfuric Acid Only, Iron to Waste - Figure 1
Green Bay

	Base Case 267,400 MTPY Pyrite 400,000 MTPY H_2SO_4	Alternate Case A 1,094,000 MTPY Pyrite 1,694,000 MTPY H_2SO_4
Capital Cost	$64,000,000	$210,000,000
Cost/Annual MT	$240.00	$192.00
Revenues/Yr	6,000,000	25,410,000
Revenues/MT of sulfuric acid	15.00	15.00
Operating Cost/Yr	16,016,000	53,835,320
Cost/MT of sulfuric acid	40.04	31.78
Gain/(loss)	(10,016,000)	(28,425,320)

Figure 11

PRODUCT ROUTE

Sulfuric Acid Only, Iron to Waste - Figure 1
Evansville

	Base Case 267,400 MTPY Pyrite 400,000 MTPY H_2SO_4	Alternate Case A 1,094,000 MTPY Pyrite 1,694,000 MTPY H_2SO_4
Capital Cost	$64,000,000	$210,000,000
Cost/Annual MT	$240.00	$192.00
Revenues/Yr	6,000,000	25,410,000
Revenues/MT	15.00	15.00
Operating Cost/Yr	20,100,000	70,504,280
Cost/MT	50.25	41.62
Gain/(loss)	(14,100,000)	(45,094,280)

PRODUCT ROUTE

Sulfuric Acid, Iron Pellets, Nonferrous Metals Reclamation - Figure 2
Green Bay

	Base Case 267,400 MTPY Pyrite 400,000 MTPY H_2SO_4 180,000 MTPY Iron Pellets	Alternate Case A 1,094,000 MTPY Pyrite 1,694,000 MTPY H_2SO_4 718,000 MTPY Iron Pellets
Capital Cost	$84,000,000	$250,000,000
Cost/Annual MT	$314.00	$229.00
Revenues/Yr*	17,258,975	70,720,750
Operating Cost/Yr	23,577,600	73,070,540
Cost/MT of sulfuric acid	40.04	31.78
Cost/MT of iron pellets	41.97	26.97
Gain/(loss)	(6,318,625)	(2,349,790)

*Includes credit for nonferrous and precious metals
Base Case - $3,698,975
Alternate Case - $15,154,750

Figure 13

PRODUCT ROUTE

Sulfuric Acid, Iron Pellets, Nonferrous Metals Reclamation - Figure 2
Evansville

	Base Case 267,400 MTPY Pyrite 400,000 MTPY H_2SO_4 180,000 MTPY Iron Pellets	Alternate Case A 1,094,000 MTPY Pyrite 1,694,000 MTPY H_2SO_4 718,000 MTPY Iron Pellets
Capital Cost	$84,000,000	$250,000,000
Cost/Annual MT	$314.00	$229.00
Revenues/Yr*	17,258,975	70,720,750
Operating Cost/Yr	27,654,600	89,739,500
Cost/MT of sulfuric acid	50.25	41.62
Cost/MT of iron pellets	41.97	26.79
Gain/(loss)	(10,395,625)	(19,018,750)

*Includes credit for nonferrous and precious metals
Base Case - $3,698,975
Alternate Case - $15,154,750

Figure 14

PROCESS ROUTE

DAP, Iron Pellets & Nonferrous Metal Recovery (Figure 3)
Green Bay

	Base Case 267,400 MTPY Pyrite 180,000 MTPY Iron Pellets 562,000 MTPY DAP	Alternate Case A 1,094,000 MTPY Pyrite 718,000 MTPY Iron Pellets 1,572,000 MTPY DAP
Capital Cost	$145,000,000	$400,000,000
Cost/Annual MT	$542.00	$365.00
Revenues/Yr*	134,898,975	391,151,750
Operating Cost/Yr	100,340,000	269,371,860
Gain/(loss)	$34,558,175	$121,778,890

*Includes credit for nonferrous and precious metals
Base Case - $3,698,975
Alternate Case A - $15,154,750

Figure 15

```
                    PYRITE PROCESSING STUDY (BASE CASE)
                  562,000 METRIC TONS/YEAR  D.A.P.   PRODUCT #1
                  180,000 METRIC TONS/YEAR IRON PELLETS  PRODUCT #2


ZERO MONTH      ZERO YEAR      LAST YEAR      NUMBER PRODUCTS      TODAYS MONTH      TODAYS YEAR      NO.YRS. BEFORE YR. ZERO
    1             1988           1999               2                    1               1983                    5


    PRODUCT NUMBER   1

    SALES VOLUME, M UNITS/YR
        0.           0.           0.           0.           0.         562.         562.         562.         562.         562.         562.         562.
      562.         562.         562.         562.         562.

    SALES PRICE, $/UNIT
      .0000        .0000        .0000        .0000        .0000    220.0000     220.0000     220.0000     220.0000     220.0000     220.0000     220.0000
  220.0000     220.0000     220.0000     220.0000     220.0000

    VARIABLE EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000       .0000        .0000        .0000        .0000        .0000        .0000        .0000
      .0000        .0000        .0000        .0000        .0000

    DISTRIBUTION EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000       .0000        .0000        .0000        .0000        .0000        .0000        .0000
      .0000        .0000        .0000        .0000        .0000

    MARKETING EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000      1.0000       1.0000       1.0000       1.0000       1.0000       1.0000       1.0000
    1.0000       1.0000       1.0000       1.0000       1.0000



    PRODUCT NUMBER   2

    SALES VOLUME, M UNITS/YR
        0.           0.           0.           0.           0.         180.         180.         180.         180.         180.         180.         180.
      180.         180.         180.         180.         180.

    SALES PRICE, $/UNIT
      .0000        .0000        .0000        .0000        .0000     42.0000      42.0000      42.0000      42.0000      42.0000      42.0000      42.0000
   42.0000      42.0000      42.0000      42.0000      42.0000

    VARIABLE EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000       .0000        .0000        .0000        .0000        .0000        .0000        .0000
      .0000        .0000        .0000        .0000        .0000

    DISTRIBUTION EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000       .0000        .0000        .0000        .0000        .0000        .0000        .0000
      .0000        .0000        .0000        .0000        .0000

    MARKETING EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000      1.0000       1.0000       1.0000       1.0000       1.0000       1.0000       1.0000
    1.0000       1.0000       1.0000       1.0000       1.0000
```

Figure 15-A1

```
  FIXED EXPENSE, $M
       0.          0.          0.          0.          0.    100341.     100341.     100341.     100341.     100341.     100341.     100341.
100341.     100341.     100341.     100341.     100341.
```

Figure 15-B1

```
R + D EXPENSE, $M
    0.          0.          0.          0.          0.       1000.       1000.       1000.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

PREOP EXPENSE, $M
  700.        700.        700.        700.        700.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

WORKING CAPITAL, $M
    0.          0.          0.          0.       2750.      33500.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.     -36250.

DEPLETION ALLOWANCE, $M
    0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

CAPITAL EXPENDITURE, $M
 7000.      35000.      50000.      35000.      18000.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

SALVAGE VALUE, $M
    0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

      CAPT. EXP.    DEPR. METH.        IN YEAR       OUT YEAR      VAL. OF K
       145000.                1           1988          1999            .00

         TAX RATE     TAX CREDIT  2ND PVP RATE
              .48            .07           .00


      EQUITY CAPT.    CAPT. INVEST.        IN YEAR          OUT YEAR      DEBT INT. RATE       INT. METHOD
           0.          145000.              1988              1999              .00                 1
```

Figure 15-C1

```
                                                FOLLOWING VALUES ARE IN $M

                                           DEPRECIA-
                                    CASH        TION                                                        CASH                 CUMULA-
                                  INCOME         FOR    INTEREST                                          INCOME                    TIVE
               GROSS       TOTAL  BEFORE         TAX          ON     TAXABLE      INCOME         TAX       AFTER        CASH        CASH
YEAR        REVENUES    EXPENSES   TAXES    PURPOSES        DEBT      INCOME         TAX     CREDITS       TAXES        FLOW        FLOW

1983          0.        700.       -700.          0.          0.          0.          0.          0.       -700.      -7700.      -7700.
1984          0.        700.       -700.          0.          0.          0.          0.          0.       -700.     -35700.     -43400.
1985          0.        700.       -700.          0.          0.          0.          0.          0.       -700.     -50700.     -94100.
1986          0.        700.       -700.          0.          0.          0.          0.          0.       -700.     -35700.    -129800.
1987          0.        700.       -700.          0.          0.          0.          0.          0.       -700.     -21450.    -151250.
1988     131200.     114166.      17034.      12083.          0.       4951.       2376.      10150.      24808.      -8692.    -159942.
1989     131200.     114166.      17034.      12083.          0.       4951.       2376.          0.      14658.      14658.    -145285.
1990     131200.     114166.      17034.      12083.          0.       4951.       2376.          0.      14658.      14658.    -130627.
1991     131200.     113166.      18034.      12083.          0.       5951.       2856.          0.      15178.      15178.    -115450.
1992     131200.     113166.      18034.      12083.          0.       5951.       2856.          0.      15178.      15178.    -100272.
1993     131200.     113166.      18034.      12083.          0.       5951.       2856.          0.      15178.      15178.     -85094.
1994     131200.     113166.      18034.      12083.          0.       5951.       2856.          0.      15178.      15178.     -69917.
1995     131200.     113166.      18034.      12083.          0.       5951.       2856.          0.      15178.      15178.     -54739.
1996     131200.     113166.      18034.      12083.          0.       5951.       2856.          0.      15178.      15178.     -39562.
1997     131200.     113166.      18034.      12083.          0.       5951.       2856.          0.      15178.      15178.     -24384.
1998     131200.     113166.      18034.      12083.          0.       5951.       2856.          0.      15178.      15178.      -9206.
1999     131200.     113166.      18034.      12083.          0.       5951.       2856.          0.      15178.      51428.      42221.


                             EARNING POWER       2.51 PERCENT


           PVP DISCOUNTED AT  8 PERCENT       -48656.


           PVP DISCOUNTED AT 15 PERCENT       -69241.


STOP     77
```

Figure 15-D1

```
                        PYRITE PROCESSING STUDY (ALTERNATE A)
                      1572,000 METRIC TONS/YEAR  D.A.P.   PRODUCT #1
                      718,000 METRIC TONS/YEAR IRON PELLETS  PRODUCT #2


ZERO MONTH      ZERO YEAR      LAST YEAR      NUMBER PRODUCTS      TODAYS MONTH      TODAYS YEAR      NO.YRS. BEFORE YR. ZERO
    1              1988           1999               2                   1               1983                    5

      PRODUCT NUMBER   1

      SALES VOLUME, M UNITS/YR
          0.          0.          0.          0.          0.       1572.       1572.       1572.       1572.       1572.       1572.       1572.
       1572.       1572.       1572.       1572.       1572.

      SALES PRICE, $/UNIT
       .0000       .0000       .0000       .0000       .0000    220.0000    220.0000    220.0000    220.0000    220.0000    220.0000    220.0000
    220.0000    220.0000    220.0000    220.0000    220.0000

      VARIABLE EXPENSE, $/UNIT
       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000
       .0000       .0000       .0000       .0000       .0000

      DISTRIBUTION EXPENSE, $/UNIT
       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000
       .0000       .0000       .0000       .0000       .0000

      MARKETING EXPENSE, $/UNIT
       .0000       .0000       .0000       .0000       .0000      1.0000      1.0000      1.0000      1.0000      1.0000      1.0000      1.0000
      1.0000      1.0000      1.0000      1.0000      1.0000


      PRODUCT NUMBER   2

      SALES VOLUME, M UNITS/YR
          0.          0.          0.          0.          0.        718.        718.        718.        718.        718.        718.        718.
        718.        718.        718.        718.        718.

      SALES PRICE, $/UNIT
       .0000       .0000       .0000       .0000       .0000     42.0000     42.0000     42.0000     42.0000     42.0000     42.0000     42.0000
     42.0000     42.0000     42.0000     42.0000     42.0000

      VARIABLE EXPENSE, $/UNIT
       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000
       .0000       .0000       .0000       .0000       .0000

      DISTRIBUTION EXPENSE, $/UNIT
       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000       .0000
       .0000       .0000       .0000       .0000       .0000

      MARKETING EXPENSE, $/UNIT
       .0000       .0000       .0000       .0000       .0000      1.0000      1.0000      1.0000      1.0000      1.0000      1.0000      1.0000
      1.0000      1.0000      1.0000      1.0000      1.0000
```

Figure 15-A2

```
   FIXED EXPENSE, $M
          0.          0.          0.          0.          0.    269372.    269372.    269372.    269372.    269372.    269372.    269372.
 269372.    269372.    269372.    269372.    269372.
```

Figure 15-B2

```
R + D EXPENSE, $M
    0.          0.          0.          0.          0.       1000.       1000.       1000.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

PREOP EXPENSE, $M
  700.        700.        700.        700.        700.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

WORKING CAPITAL, $M
    0.          0.          0.          0.       4000.      96000.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.    -100000.

DEPLETION ALLOWANCE, $M
    0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

CAPITAL EXPENDITURE, $M
50000.      75000.     100000.     100000.      75000.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

SALVAGE VALUE, $M
    0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

    CAPT. EXP.   DEPR. METH.        IN YEAR       OUT YEAR     VAL. OF K
     400000.               1           1988           1999           .00

      TAX RATE     TAX CREDIT   2ND PVP RATE
           .48            .07            .02


    EQUITY CAPT.    CAPT. INVEST.        IN YEAR          OUT YEAR      DEBT INT. RATE       INT. METHOD
          0.           400000.             1988              1999                 .00                1
```

Figure 15-C2

```
                                FOLLOWING VALUES ARE IN $M

                                       DEPRECIA-
                                 CASH       TION                                                  CASH               CUMULA-
                               INCOME        FOR   INTEREST                                     INCOME                  TIVE
          GROSS      TOTAL     BEFORE        TAX         ON    TAXABLE     INCOME        TAX      AFTER       CASH       CASH
YEAR   REVENUES   EXPENSES      TAXES   PURPOSES       DEBT     INCOME        TAX    CREDITS      TAXES       FLOW       FLOW

1983         0.       700.      -700.         0.         0.         0.         0.         0.      -700.    -50700.    -50700.
1984         0.       700.      -700.         0.         0.         0.         0.         0.      -700.    -75700.   -126400.
1985         0.       700.      -700.         0.         0.         0.         0.         0.      -700.   -100700.   -227100.
1986         0.       700.      -700.         0.         0.         0.         0.         0.      -700.   -100700.   -327800.
1987         0.       700.      -700.         0.         0.         0.         0.         0.      -700.    -79700.   -407500.
1988    375996.    305995.     70001.     33333.         0.     36667.     17600.     28000.     80400.    -15600.   -423100.
1989    375996.    305995.     70001.     33333.         0.     36667.     17600.         0.     52400.     52400.   -370699.
1990    375996.    305995.     70001.     33333.         0.     36667.     17600.         0.     52400.     52400.   -318299.
1991    375996.    304995.     71001.     33333.         0.     37667.     18080.         0.     52920.     52920.   -265379.
1992    375996.    304995.     71001.     33333.         0.     37667.     18080.         0.     52920.     52920.   -212458.
1993    375996.    304995.     71001.     33333.         0.     37667.     18080.         0.     52920.     52920.   -159538.
1994    375996.    304995.     71001.     33333.         0.     37667.     18080.         0.     52920.     52920.   -106618.
1995    375996.    304995.     71001.     33333.         0.     37667.     18080.         0.     52920.     52920.    -53697.
1996    375996.    304995.     71001.     33333.         0.     37667.     18080.         0.     52920.     52920.      -777.
1997    375996.    304995.     71001.     33333.         0.     37667.     18080.         0.     52920.     52920.     52143.
1998    375996.    304995.     71001.     33333.         0.     37667.     18080.         0.     52920.     52920.    105064.
1999    375996.    304995.     71001.     33333.         0.     37667.     18080.         0.     52920.    152920.    257984.


                    EARNING POWER     5.32 PERCENT


      PVP DISCOUNTED AT  8 PERCENT      -67937.


      PVP DISCOUNTED AT 15 PERCENT     -153276.


STOP    77
```

Figure 15-D2

PROCESS ROUTE

DAP, Iron Pellets & Nonferrous Metal Recovery (Figure 3)
Evansville

	Base Case 267,400 MTPY Pyrite 180,000 MTPY Iron Pellets 562,000 MTPY DAP	Alternate Case A 1,094,000 MTPY Pyrite 718,000 MTPH H_2SO_4 1,572,000 MTPY DAP
Capital Cost	$145,000,000	$400,000,000
Cost/Annual MT	$542.00	$365.00
Revenues/Yr*	134,698,975	391,151,750
Operating Cost/Yr	101,245,620	277,231,860
Iron Pellets/MT	41.97	26.79
DAP	166.71	164.12
Gain/(loss)	33,453,355	113,919,890

*Includes credit for nonferrous and precious metals
Base Case - $3,698,975
Alternate Case A - $15,154,750

Figure 16

PROCESS ROUTE

DAP, IRON PELLETS & NONFERROUS METAL RECOVERY
GREEN BAY

ALTERNATE CASE B & B-1
No Zinc Refinery Sulfuric Acid

	Alternate Case B 400,000 MTPY Sulfuric Acid 180,000 MTPY Iron Pellets 313,000 MTPY DAP	Alternate Case B-1 1,694,000 MTPY Sulfuric Acid 718,000 MTPY Iron Pellets 1,322,228 MTPY DAP
Capital Cost	$133,000,000	$392,000,000
Revenues/Yr*	80,118,975	336,200,750
Operating Cost/Yr	64,849,250	237,601,174
Iron Pellets/MT	41.97	26.79
DAP/MT	183.05	165.15
Gain/(Loss)	15,269,725	98,599,576

*Includes credit for nonferrous and precious metals
267,400 MTPY Pyrite - $3,648,975
1,094,000 MTPY Pyrite - $15,154,750

Figure 17

```
                         PYRITE PROCESSING STUDY (ALTERNATE B)
                        313,000 METRIC TONS/YEAR  D.A.P.   PRODUCT #1
                        180,000 METRIC TONS/YEAR IRON PELLETS  PRODUCT #2

ZERO MONTH      ZERO YEAR      LAST YEAR      NUMBER PRODUCTS      TODAYS MONTH      TODAYS YEAR      NO.YRS. BEFORE YR. ZERO
    1             1988           1999                2                   1               1983                  5

   PRODUCT NUMBER   1

   SALES VOLUME, M UNITS/YR
      0.          0.          0.          0.          0.        313.        313.        313.        313.        313.        313.        313.
    313.        313.        313.        313.        313.

   SALES PRICE, $/UNIT
    .0000       .0000       .0000       .0000       .0000   220.0000    220.0000    220.0000    220.0000    220.0000    220.0000    220.0000
 220.0000    220.0000    220.0000    220.0000    220.0000

   VARIABLE EXPENSE, $/UNIT
    .0000       .0000       .0000       .0000       .0000      .0000       .0000       .0000       .0000       .0000       .0000       .0000
    .0000       .0000       .0000       .0000       .0000

   DISTRIBUTION EXPENSE, $/UNIT
    .0000       .0000       .0000       .0000       .0000      .0000       .0000       .0000       .0000       .0000       .0000       .0000
    .0000       .0000       .0000       .0000       .0000

   MARKETING EXPENSE, $/UNIT
    .0000       .0000       .0000       .0000       .0000     1.0000      1.0000      1.0000      1.0000      1.0000      1.0000      1.0000
   1.0000      1.0000      1.0000      1.0000      1.0000


   PRODUCT NUMBER   2

   SALES VOLUME, M UNITS/YR
      0.          0.          0.          0.          0.        180.        180.        180.        180.        180.        180.        180.
    180.        180.        180.        180.        180.

   SALES PRICE, $/UNIT
    .0000       .0000       .0000       .0000       .0000    42.0000     42.0000     42.0000     42.0000     42.0000     42.0000     42.0000
  42.0000     42.0000     42.0000     42.0000     42.0000

   VARIABLE EXPENSE, $/UNIT
    .0000       .0000       .0000       .0000       .0000      .0000       .0000       .0000       .0000       .0000       .0000       .0000
    .0000       .0000       .0000       .0000       .0000

   DISTRIBUTION EXPENSE, $/UNIT
    .0000       .0000       .0000       .0000       .0000      .0000       .0000       .0000       .0000       .0000       .0000       .0000
    .0000       .0000       .0000       .0000       .0000

   MARKETING EXPENSE, $/UNIT
    .0000       .0000       .0000       .0000       .0000     1.0000      1.0000      1.0000      1.0000      1.0000      1.0000      1.0000
   1.0000      1.0000      1.0000      1.0000      1.0000
```

Figure 17-A1

```
FIXED EXPENSE, $M
      0.          0.          0.          0.          0.      64849.      64849.      64849.      64849.      64849.      64849.      64849.
 64849.      64849.      64849.      64849.      64849.
```

Figure 17-B1

```
R + D EXPENSE, $M
    0.          0.          0.          0.          0.       1000.       1000.       1000.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

PREOP EXPENSE, $M
  700.        700.        700.        700.        700.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

WORKING CAPITAL, $M
    0.          0.          0.          0.       2750.      33750.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.     -36250.

DEPLETION ALLOWANCE, $M
    0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

CAPITAL EXPENDITURE, $M
 7000.      35000.      38000.      35000.      18000.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

SALVAGE VALUE, $M
    0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
    0.          0.          0.          0.          0.

        CAPT. EXP.   DEPR. METH.       IN YEAR       OUT YEAR      VAL. OF K
         133000.               1          1988           1999            .00

           TAX RATE     TAX CREDIT  2ND PVP RATE
                .48            .07           .00

        EQUITY CAPT.   CAPT. INVEST.        IN YEAR          OUT YEAR       DEBT INT. RATE      INT. METHOD
                  0.         133000.           1988              1999                  .00                1
```

Figure 17-C1

```
                                   FOLLOWING VALUES ARE IN $M

                                              DEPRECIA-
                                   CASH            TION                                                 CASH                 CUMULA-
                                 INCOME             FOR   INTEREST                                    INCOME                    TIVE
          GROSS      TOTAL       BEFORE             TAX         ON    TAXABLE     INCOME        TAX    AFTER       CASH       CASH
YEAR   REVENUES   EXPENSES        TAXES        PURPOSES       DEBT     INCOME        TAX    CREDITS    TAXES       FLOW       FLOW

1983         0.       700.        -700.              0.         0.         0.         0.         0.    -700.     -7700.     -7700.
1984         0.       700.        -700.              0.         0.         0.         0.         0.    -700.    -35700.    -43400.
1985         0.       700.        -700.              0.         0.         0.         0.         0.    -700.    -38700.    -82100.
1986         0.       700.        -700.              0.         0.         0.         0.         0.    -700.    -35700.   -117800.
1987         0.       700.        -700.              0.         0.         0.         0.         0.    -700.    -21450.   -139250.
1988     76420.     77425.       -1005.          11083.         0.    -12089.         0.      9310.    8305.    -25445.   -164695.
1989     76420.     77425.       -1005.          11083.         0.    -12089.         0.         0.   -1005.     -1005.   -165701.
1990     76420.     77425.       -1005.          11083.         0.    -12089.         0.         0.   -1005.     -1005.   -166706.
1991     76420.     76425.          -5.          11083.         0.    -11089.         0.         0.      -5.        -5.   -166711.
1992     76420.     76425.          -5.          11083.         0.    -11089.         0.         0.      -5.        -5.   -166717.
1993     76420.     76425.          -5.          11083.         0.    -11089.         0.         0.      -5.        -5.   -166722.
1994     76420.     76425.          -5.          11083.         0.    -11089.         0.         0.      -5.        -5.   -166727.
1995     76420.     76425.          -5.          11083.         0.    -11089.         0.         0.      -5.        -5.   -166733.
1996     76420.     76425.          -5.          11083.         0.    -11089.         0.         0.      -5.        -5.   -166738.
1997     76420.     76425.          -5.          11083.         0.    -11089.         0.         0.      -5.        -5.   -166743.
1998     76420.     76425.          -5.          11083.         0.    -11089.         0.         0.      -5.        -5.   -166749.
1999     76420.     76425.          -5.          11083.         0.    -11089.         0.         0.      -5.     36245.   -130504.


                        EARNING POWER    -7.44 PERCENT


       PVP DISCOUNTED AT  8 PERCENT      -121290.


       PVP DISCOUNTED AT 15 PERCENT      -105779.


STOP    77
```

Figure 17-D1

```
                                   PYRITE PROCESSING STUDY (ALTERNATE-B1)
                                1,322,228 METRIC TONS/YEAR  D.A.P.   PRODUCT #1
                                718,000 METRIC TONS/YEAR IRON PELLETS  PRODUCT #2


ZERO MONTH       ZERO YEAR       LAST YEAR       NUMBER PRODUCTS       TODAYS MONTH       TODAYS YEAR       NO.YRS. BEFORE YR. ZERO
    1               1988            1999                2                    1                1983                     5


     PRODUCT NUMBER   1

     SALES VOLUME, M UNITS/YR
        0.           0.           0.           0.           0.        1322.        1322.        1322.        1322.        1322.        1322.        1322.
     1322.        1322.        1322.        1322.        1322.

     SALES PRICE, $/UNIT
      .0000        .0000        .0000        .0000        .0000    220.0000     220.0000     220.0000     220.0000     220.0000     220.0000     220.0000
  220.0000     220.0000     220.0000     220.0000     220.0000

     VARIABLE EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000       .0000        .0000        .0000        .0000        .0000        .0000        .0000
      .0000        .0000        .0000        .0000        .0000

     DISTRIBUTION EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000       .0000        .0000        .0000        .0000        .0000        .0000        .0000
      .0000        .0000        .0000        .0000        .0000

     MARKETING EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000      1.0000       1.0000       1.0000       1.0000       1.0000       1.0000       1.0000
    1.0000       1.0000       1.0000       1.0000       1.0000



     PRODUCT NUMBER   2

     SALES VOLUME, M UNITS/YR
        0.           0.           0.           0.           0.         718.         718.         718.         718.         718.         718.         718.
      718.         718.         718.         718.         718.

     SALES PRICE, $/UNIT
      .0000        .0000        .0000        .0000        .0000     42.0000      42.0000      42.0000      42.0000      42.0000      42.0000      42.0000
   42.0000      42.0000      42.0000      42.0000      42.0000

     VARIABLE EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000       .0000        .0000        .0000        .0000        .0000        .0000        .0000
      .0000        .0000        .0000        .0000        .0000

     DISTRIBUTION EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000       .0000        .0000        .0000        .0000        .0000        .0000        .0000
      .0000        .0000        .0000        .0000        .0000

     MARKETING EXPENSE, $/UNIT
      .0000        .0000        .0000        .0000        .0000      1.0000       1.0000       1.0000       1.0000       1.0000       1.0000       1.0000
    1.0000       1.0000       1.0000       1.0000       1.0000
```

Figure 17-A2

```
  FIXED EXPENSE, $M
        0.          0.          0.          0.          0.    237501.     237601.     237601.     237601.     237601.     237601.     237601.
237601.     237601.     237601.     237601.     237601.
```

Figure 17-B2

```
R + D EXPENSE, $M
     0.          0.          0.          0.          0.       1000.       1000.       1000.          0.          0.          0.          0.
     0.          0.          0.          0.          0.

PREOP EXPENSE, $M
   700.        700.        700.        700.        700.          0.          0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          0.

WORKING CAPITAL, $M
     0.          0.          0.          0.       3200.      85000.          0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.     -88200.

DEPLETION ALLOWANCE, $M
     0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          0.

CAPITAL EXPENDITURE, $M
 42000.      75000.     100000.     100000.      75000.          0.          0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          0.

SALVAGE VALUE, $M
     0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.          0.
     0.          0.          0.          0.          0.

    CAPT. EXP.    DEPR. METH.        IN YEAR      OUT YEAR      VAL. OF K
      392000.               1           1988          1999            .00

      TAX RATE     TAX CREDIT   2ND PVP RATE
           .48            .07            .03


    EQUITY CAPT.    CAPT. INVEST.        IN YEAR          OUT YEAR      DEBT INT. RATE       INT. METHOD
         0.          392000.             1988             1999               .00                 1
```

Figure 17-C2

```
                                        FOLLOWING VALUES ARE IN $M

                                               DEPRECIA-
                                         CASH      TION                                                      CASH                  CUMULA-
                                       INCOME       FOR   INTEREST                                         INCOME                     TIVE
               GROSS        TOTAL      BEFORE       TAX         ON    TAXABLE      INCOME         TAX       AFTER        CASH         CASH
YEAR        REVENUES     EXPENSES       TAXES  PURPOSES       DEBT     INCOME         TAX     CREDITS       TAXES        FLOW         FLOW


1983              0.         700.       -700.        0.         0.         0.          0.          0.       -700.     -42700.      -42700.
1984              0.         700.       -700.        0.         0.         0.          0.          0.       -700.     -75700.     -118400.
1985              0.         700.       -700.        0.         0.         0.          0.          0.       -700.    -100700.     -219100.
1986              0.         700.       -700.        0.         0.         0.          0.          0.       -700.    -100700.     -319800.
1957              0.         700.       -700.        0.         0.         0.          0.          0.       -700.     -78900.     -398700.
1988         321046.      273308.      47738.    32667.         0.     15072.       7234.      27440.      67944.     -17056.     -415756.
1989         321046.      273308.      47738.    32667.         0.     15072.       7234.          0.      40504.      40504.     -375252.
1990         321046.      273308.      47738.    32667.         0.     15072.       7234.          0.      40504.      40504.     -334748.
1991         321046.      272308.      48738.    32667.         0.     16072.       7714.          0.      41024.      41024.     -293724.
1992         321046.      272308.      48738.    32667.         0.     16072.       7714.          0.      41024.      41024.     -252701.
1993         321046.      272308.      48738.    32667.         0.     16072.       7714.          0.      41024.      41024.     -211677.
1994         321046.      272308.      48738.    32667.         0.     16072.       7714.          0.      41024.      41024.     -170653.
1995         321046.      272308.      48738.    32667.         0.     16072.       7714.          0.      41024.      41024.     -129629.
1996         321046.      272308.      48738.    32667.         0.     16072.       7714.          0.      41024.      41024.      -88605.
1997         321046.      272308.      48738.    32667.         0.     16072.       7714.          0.      41024.      41024.      -47581.
1998         321046.      272308.      48738.    32667.         0.     16072.       7714.          0.      41024.      41024.       -6557.
1999         321046.      272308.      48738.    32667.         0.     16072.       7714.          0.      41024.     129224.      122667.



                        EARNING POWER      2.81 PERCENT


         PVP DISCOUNTED AT  8 PERCENT      -119572.


         PVP DISCOUNTED AT 15 PERCENT      -176126.


STOP     77
```

Figure 17-D2

PROCESS ROUTE

DAP, IRON PELLETS & NONFERROUS METAL RECOVERY
EVANSVILLE

ALTERNATE CASE B & B-1
No Zinc Refinery Sulfuric Acid

	Alternate Case B 400,000 MTPY Sulfuric Acid 180,000 MTPY Iron Pellets 313,000 MTPY DAP	Alternate Case B-1 1,694,000 MTPY Sulfuric Acid 718,000 MTPY Iron Pellets 1,322,228 MTPY DAP
Capital Cost	$133,000,000	$392,000,000
Revenues/Yr*	80,118,975	336,200,750
Operating Cost/Yr	67,403,330	246,922,882
Iron Pellets/MT	41.97	26.79
DAP/MT	191.21	172.20
Gain/(Loss)	12,715,645	89,277,868

*Includes credit for nonferrous and precious metals
267,400 MTPY Pyrite - $3,698,925
1,094,000 MTPY Pyrite - $15,154,750

Figure 18

Table 4 - United States: Sulfur Supply Forecast
(1000 metric tons)

	1978	1980	1985	1990	2000
TOTAL	11,168	12,748	13,558	16,500	22,850
Frasch	5,648	6,300	5,700	5,050	3,000
Recovered	4,055	4,678	5,478	8,150	15,400
(1) Natural gas	1,752	1,800	2,000	1,800	1,200
(2) Refinery	2,303	2,853	3,403	4,000	5,500
(3) Power plants	15	15	25	750	2,000
(4) Coal processing	5	5	50	1,400	6,200
(5) Oil shales/tar sands	-	-		200	500
Byproduct H_2SO_4	1,103*	1,320	2,200	3,100	4,200
Pyrite	301	200	100	100	-
Other forms	61	70	80	100	250
Reclaimed sulfuric acid	-	700	850	950	1,600

*excludes 613,000 metric tons of reclaimed H_2SO_4 from petroleum refining and coal production

Source CRU estimates

U.S. Current and Projected Demand

For the third consecutive year, apparent consumption of sulfur in all forms exceeded domestic production. Apparent consumption of sulfur in all forms attained record levels of 12,600,000 metric tons in 1978, an 8% increase on the previous year.

3.4 MARKET FOR SULFURIC ACID

Introduction

Sulfuric acid is the largest tonnage industrial chemical in the United States with production totalling 35,653,000 metric tons in 1978. Sulfuric acid is used in most industrial sectors but the phosphate fertilizer industry accounts for the major share - 60%, the balance of consumption is spread between a wide range of industries - petroleum refining, 5%; copper leaching, 5%; titanium oxide, 3%; hydrofluoric acid, 2%; alcohols, 2%; explosives, 2%; aluminum sulfate, 2%; ammonium sulfate, 2%; iron and steel pickling, 2%; cellulosics, 2%; uranium milling, 2%; surface active agents, 1%; others, 12%. In view of the wide range of end uses, sulfuric acid is often considered as an economic indicator. Sulfuric acid is particularly responsive to rapid changes in supply and demand largely because of the expense and difficulty of storing the product. Consequently inventories are kept at a minimum. Although buffered to some extent by the wide variety of outlets, in view of their relatively small individual market size, the fortunes of the sulfuric acid industry have been dependent upon phosphate fertilizers.

Sulfuric Acid Capacity

At the beginning of 1979, there were 73 companies producing sulfuric acid at 133 locations, with a total nameplate capacity of over 51,000,000 metric tons of 100% H_2SO_4.

Table 5 - U.S. Sulfuric Acid Capacity and Operating Rates
(1000 MTPY, 100% H_2SO_4)

	Capacity	Operating Rate %
1960	20,475	76
1965	22,755	95
1970	35,380	73
1971	35,712	71
1972	36,529	74
1973	37,338	75
1974	38,570	79
1975	40,882	69
1976	42,072	69
1977	43,327	72
1978	45,560	77

Source: SRI

Of the above capacity, 81% is produced from elemental sulfur feedstocks, 8% from sludge acids, 8% from smelter gases and 3% from other sources - H_2S, pyrite, etc.

Capacity is currently well in excess of production, from its peak operating rate of 95% in the mid 1960s operating rates have since fluctuated between 69-80% of total capacity. Prior to 1970, the typical operating level was generally 75-80%. However, several factors in the '70s have affected these rates: (1) A substantial incremental capacity has been introduced due to the construction of byproduct acid plants particularly at copper smelters. Operating rates at such plants have generally been low as copper producers have invested in excess capacity so as not to inhibit metal production. (2) The main market for sulfuric acid is the phosphate fertilizer sector and consequently the operating rates in the acid sector have paralled those of phosphate plants.

Sulfuric Acid Production

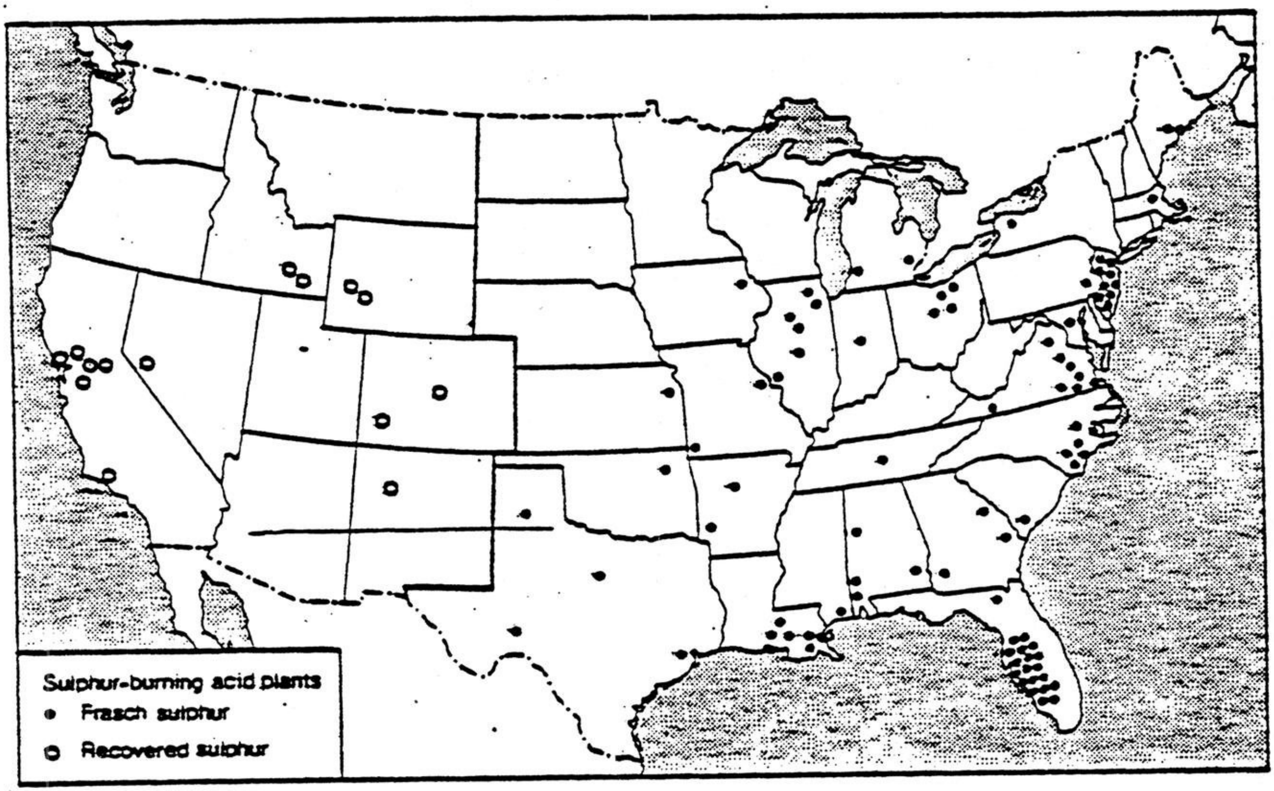
Total sulfuric acid production has grown from 14,746,370 metric tons of 100% H_2SO_4 to 35,912,000 between 1955 and 1978. Three market phases can be identified: (1) the slow but steady growth over the period up to 1973; (2) the pre-fertilizer price hike growth in 1974 and the consequent stagnation in 1975 and 1976; (3) over the past 2 years, spurred on by the growth in the phosphate fertilizer sector, output has increased by 5.7 million metric tons 100% H_2SO_4.

As can be seen from Table 7, production of sulfuric acid by the contact process now dominates the industry. In 1955, of the 13.9 million metric tons of new acid production, 85% was via the contact process; by 1976 (the last year for which chamber process production was recorded) this had increased to over 99% - with only two chamber process plants remaining. The balance comprises fortified acid.

In terms of production by sulfur source, elemental sulfur accounts for the major share. In 1977, the burning of elemental sulfur by acid plants accounted for 88% of total output of new acid. Of the remaining 12% supplied by other sources, smelter gases accounted for 10% (of which copper represented 7% of the total) with H_2S and pyrite the remaining 2%. There are several other small sources which have not been identified separately - SO_2, $FeSO_4$ and coke oven gases.

Geographic distribution of sulphur terminals

Figure 3



Geographic distribution of sulphur-burning acid plants (1978)

Figure 4

Table 6 - H_2SO_4 Production by Sulfur Source
(1000 metric tons of 100% H_2SO_4)

	NEW ACID				
	FROM NEW SULFUR				
	Elemental S	H_2S	Smelter Gas	Pyrite	Total
1955	10,493	308	1,009	1,467	13,277
1960	11,180	599	1,074	1,547	14,400
1965	16,658	844	1,207	1,252	19,961
1970	20,531	611	1,668	1,134	23,944
1971	20,420	544	1,610	1,080	23,654
1972	22,633	499	1,696	807	25,635
1973	23,666	453	1,863	513	26,495
1974	26,034	408	2,033	392	28,867
1975	23,532	363	2,382	572	26,849
1976	23,643	318	2,928	690	27,597
1977	25,983	272	2,936	399	29,590
1978	N/A	N/A	N/A	N/A	N/A

	NEW ACID				
	FROM NEW SULFUR				
	Total	Sludge Acids*	Total	Fortified Acids*	Total Acid
1955	13,277	620	13,897	849	14,746
1960	14,400	1,099	15,499	724	16,223
1965	19,961	1,642	21,603	942	22,545
1970	23,944	1,694	25,638	1,148	26,786
1971	23,654	1,527	25,181	1,159	26,340
1972	25,635	1,561	27,196	1,091	28,287
1973	26,495	1,446	27,941	1,042	28,983
1974	28,867	1,453	30,320	684	31,004
1975	26,849	1,442	28,291	1,066	29,357
1976	27,479	1,451	29,030	1,181	30,211
1977	29,590	1,399	30,989	1,510	32,499
1978	N/A	N/A	34,720	933	35,653

Source: SRI

Note: *1. Sludge acids, i.e., virgin acid produced by decomposition of spent acid from petroleum refining, sulfanation and petrochemical processes.

2. Recovered acids - brought back to strength by blending with new acid or oleum or concentrated and distilled.

Table 7 - H_2SO_4 Production by Process and by Strength
(1000 metric tons of 100% H_2SO_4)

	BY PROCESS NEW			BY STRENGTH*			
	Chamber	Contact	Total	Fortified	100% H_2SO_4	Oleum(1)	Total
1955	2,106	11,792	13,989	849	11,026	1,615	14,747
1960	1,706	13,794	15,500	724	12,850	1,667	16,224
1965	1,155	20,447	21,602	942	19,407	1,982	22,544
1970	291	25,346	25,637	1,148	23,807	2,686	26,785
1971	191	24,989	25,180	1,159	23,915	2,234	26,339
1972	130	27,198	27,328	1,091	25,799	2,362	28,419
1973	97	27,844	27,941	1,042	26,355	2,532	28,983
1974	119	30,202	30,321	676	28,428	4,314	30,997
1975	88	28,203	28,291	1,066	27,380	1,890	29,357
1976	73	28,952	29,029	1,181	28,282	1,513	30,210
1977	N/A	N/A	30,986	1,510	30,553	1,636	32,496
1978	N/A	N/A	34,720	933	N/A	N/A	35,653

Source: USDC
Note: *Contact only.

(1) Oleum or fuming sulfuric acid contains free SO_3 dissolved in the acid. Can be expressed in terms of percentage H_2SO_4 equivalent.

Sulfuric Acid Consumption

In 1978, consumption of sulfuric acid in the United States totaled 37 million metric tons of 100% H_2SO_4, a 9.5% increase on the previous year.

The fertilizer industry has remained the major end user of sulfuric acid. In 1978, fertilizer production consumed over 24 million metric tons 100% H_2SO_4 or 65% of the total. The development of the fertilizer sector has been one of the main factors promoting the growth of sulfuric acid consumption. Usage by the fertilizer sector has increased by 350% since 1960, when the industry accounted for only 39% of usage.

The major growth factor in the fertilizer sector has been the emergence of the phosphoric acid industry. As detailed in Table 9, consumption of sulfuric acid used in the production of phosphoric acid has increased from 3.3 million metric tons in 1960 to 21.8 million metric tons in 1978. The spectacular increase in the growth of consumption of phosphoric acid has almost been matched by the decline of consumption in the production of single superphosphates.

Table 8 - Distribution of Sulfuric Acid by End Use

	1960	1965	1970	1978
Total	100.0%	100.0%	100.0%	100.0%
Fertilizers	39.4	46.6	60.8	65.0
Petroleum refining	8.7	8.3	7.0	4.5
Copper	N/A	N/A	2.6	4.9
Alcohols	8.9	7.9	6.2	2.9
Titanium dioxide	8.9	6.6	5.5	2.4
Hydrofluoric acid	2.6	2.6	3.2	2.1
Aluminum sulfate	2.5	2.2	2.1	1.7
Others	29.0	25.8	12.6	16.5

Outside of the fertilizer sector, the second major area of usage is in leaching of low grade copper ores where usage in 1978 reached 1.8 million metric tons. The use of sulfuric acid in petroleum refining has declined marginally over the years. In effect the petroleum refining industry is largely a recycling industry, with consumption in one form or another being negligible. The consumption of sulfuric acid by the other industries remains stable, although its consumption in the production of alcohols and titanium has declined.

Table 9 - Consumption of Sulfuric Acid by Fertilizers
(1000 metric tons of 100% H_2SO_4)

Year	Phosphoric Acid	Single Super-Phosphate	Ammonium Sulfate	Others	Total
1960	3,306	2,057	1,308	308	6,979
1965	7,225	1,808	1,696	406	11,135
1970	11,581	1,088	1,472	386	14,527
1971	12,514	1,017	1,340	376	15,247
1972	14,410	1,100	1,293	380	17,183
1973	14,767	1,005	1,455	425	17,652
1974	15,433	1,133	1,506	496	18,568
1975	17,267	786	1,467	415	19,935
1976	18,027	622	1,406	407	20,462
1977	20,567	552	1,477	419	23,015
1978	21,854	467	1,420	408	24,149

Source: SRI

Total shipments of sulfuric acid exceed the level of production with respect to deliveries of acid used in the oil refinery alkylation processes, steel pickling, nitric acid concentration, etc., and then reshipped as "spent acid" for use in other sectors. The main source of so called "spent acid" is the oil refinery industry while its main uses are in the regeneration of concentrated sulfuric acid by burning waste acid in a sulfuric acid plant, purification by hydrolysis, concentration by evaporation or fortification by the addition of SO_3.

Pricing Patterns

Sulfuric acid prices are normally quoted list price ex manufacturing facility. Historically actual prices have been contracted at levels considerably below listed prices. Discounts are available for large accounts, contract customers, and to match specific competition.

Table 10 - Sulfuric Acid List Price
($ per metric ton)

	East Coast
1968	31.4
1970	31.4
1971	30.6
1972	30.6
1974	37.0
1975	42.3
1976	42.3
1977	42.3
1978	48.3
1979	54.0

Note: In mid 1979 list prices for other regions are as follows:

Gulf Coast	47.9
Midwest	51.4
West Coast	52.4

Source: Chemical Marketing Reporter

In order to illustrate the discrepancy between list prices and actual prices, it is necessary to compare the prices quoted in Table 10, with the average shipment value recorded by the United States Department of Agriculture in Table 11.

Table 11 - U.S. Sulfuric Acid Shipment Value
($ per metric ton)

	All Shipments	Interplant Transfers[1]	Commercial Shipments
1955	17.44		
1960	N/A		
1965	15.12		
1970	17.29		
1971	17.36		
1972	16.53		
1973	16.64	15.50	16.79
1974	21.20	20.66	21.23
1975	29.37	28.70	29.43
1976	28.07	27.09	29.07
1977	30.00	30.68	29.90
1978			

Source: USDC

Note:
[1] Company transfers from primary plant to downstream plant.

As can be seen, throughout the 1970s average shipment values have been well below the prevailing list prices. The sale price for larger transactions has in fact been below the average value of all shipments which has been boosted by the inclusion of all sales, oleum and other premium grades.

The price structure of the sulfuric acid industry is particularly complex as the market is dominated by two groups of producers with vastly differing sales considerations.

(1) Virgin producers, i.e., those operations based upon sulfur burning. Even within this group there are two distinct types of producers: (a) those based upon local recovered sulfur supplies and having less expensive feedstocks; (b) those based upon Frasch sulfur - which itself is a voluntary production product. Virgin producers are voluntary acid manufacturers, for whom acid is their primary sales product.

(2) Smelter acid producers - are involuntary producers - mainly smelters, for whom acid is a byproduct disposal problem.

The situation has been one in which voluntary producers have been caught in a cost/price crisis. Faced with increasing sulfur prices, they have been forced to cut their prices in order to compete with smelter acid producers.

This is amply evidenced in Table 12, in which prices in Arizona reflect the abundance of smelter acid supplies. Historically the problem was less severe for virgin producers as sulfur supplies were relatively inexpensive and smelter acid producers tended to serve the total markets. However, as sulfur prices increased, and under the pressure of a buoyant copper market, mountain states' smelters were forced to look further afield for markets to ensure disposal of their byproduct acid. Because of their low "production cost," smelter acid producers were able to remain competitive over longer distances, and have been prepared to sell their product at prices substantially below those of virgin producers. In actual terms, Arizona smelters have been prepared to sell acid for as little as $6/MT F.O.B. to Nebraska and Kansas. Indeed in extreme cases, where smelters have had insufficient onsite storage, they have been prepared to move acid for as little as $3/MT rather than jeopardize metal production. As a result current smelter acid spot prices are in the order of $6-18/MT 100% tanks, Western works $14-16/MT 100% tanks Gulf and $7-18/MT 100% tanks, New Mexico, while inland Cities Services are selling $22.75/MT F.O.B. Copperhill, Tennessee.

These spot market prices for smelter acid can be compared to list prices of $57-60.80 West Coast; $52.75-55.75 U.S. Gulf; and $58.65 Mid West for Virgin acid (acid from sulfur).

Future Market for Sulfuric Acid

By the end of 1978, there were some 187 power plants in the United States thought to be out of compliance with the current applicable emissions regulations. The total level of SO_2 emissions from these plants equates to a sulfuric acid production of 15.87 million metric tons of 100% H_2SO_4. The total potential abatement byproduct acid from this source would account for 45% of total current acid production. However, as a number of plants would close down, others would purchase fuel of low sulfur content, and others would opt for limestone scrubbing. EPA/TVA project production of sulfuric acid at between 2,317,540 metric tons and 5,075,680 metric tons.

Having established the level of potential abatement acid production at between 2.3 and 5 million metric tons H_2SO_4, the other major source of supply will be smelter byproduct acid. Capacity of smelter acid is estimated to be in the order 5.4 million metric tons with a further 500,000 metric tons to be commissioned in 1979. The balance of capacity comprises sulfur burning and sludge acid plants.

With this background and the expected increased movement of Canadian smelter acid into the United States, there seems to be little alternative to a prolonged period of potential oversupply in the U.S./North American acid market. There is, however, some potential for a slight easing of the situation.

(1) The reduction in sulfur burning capacity in the short term continues as elemental sulfur prices continue to firm. However, the supply of recovered elemental sulfur is expected to become a major sulfur source by the 1980s and may mitigate extensive closures.

(2) The closure of some acid plants in the face of compliance with emission control regulations - as in the case of Allied, which closed its 200,000 metric tons H_2SO_4 Cleveland plant in 1973.

(3) The failure of abatement acid production to reach production levels anticipated by the EPA/TVA.

In view of the oversupply situation which is expected to continue well into the 1980s there will be little hope for producers to exert much upward pressure on prices. This will become more evident as byproduct producers expand their share of the market. Inevitably this will act as a depressant to any price increases which may be proposed by the sulfur virgin acid producers in response to higher sulfur prices.

In an evaluation of the future sulfuric acid prices that would be expected by a potential producer, a number of important factors must be taken into consideration.

(1) Exxon's sulfuric acid will be involuntary and any sales/marketing program must consider that this material poses a byproduct disposal problem, and eventually a potential production bottleneck. As detailed earlier, distress sales by mountain states' smelters have been made to California markets for as little as $3/MT F.O.B. as the necessity to dispose of the acid due to insufficient onsite storage has over-ridden all other factors. The philosophy that sulfuric acid is merely a byproduct problem should not, however, deter the involuntary producer from attempting to obtain a high net back on the acid. However, it must be evaluated realistically alongside the potential bottleneck problems from failure to dipsose of the acid.

(2) Potential disposal problems will undoubtedly arise from fluctuating levels of production because sulfuric acid production is dependent upon the vagaries of metal processing or pollution control. It is therefore unlikely that any new smelter acid producer could expect any major consumer to pay near list prices for smelter acid, for which neither the composition nor production could be guaranteed.

(3) Competition from other acid producers - the expected weak market conditions will force smelter acid producers to accept lower net backs, because of their unfavorable locations compared to virgin acid producers. Exxon's main competition will not come from virgin acid producers but from other smelter acid operations. As stated earlier, mountain states' producers are prepared to accept net backs of only $6.00/MT as they are forced to seek markets as far away as Nebraska and Kansas. The expansion of production in the mountain state areas will undoubtedly force smelter producers to look to the Mid West market. The other major competitor will be the Canadian industry. Canadian smelter acid directed towards the Mid West will increase substantially as C-I-L Inc. expands its range of suppliers and develops its market penetration. Net backs on Canadian acid are estimated to be slightly higher in certain cases than those of the New Mexico and Arizona smelters. In Table 12 estimated net backs for Canadian smelter acid for delivery to the North Central region are presented.

Table 12 - Estimated Net Backs for Canadian Smelter Acid
(1979 $ per metric ton)

	West North Central	East North Central
INCO	10	16
Noranda	5	11
Texasgulf	4	10

Exxon would be faced with a highly competitive market in the north central states by the mid 1980s. In view of its potential position as a new supplier of smelter acid, it is the opinion that Exxon could not expect its potential net back to be related to the prevailing list prices or to the net backs achieved by virgin acid producers.

In the present climate of price cutting in the north central states area, prices are in the order of $35 per metric ton delivered, in spite of list prices of $58/MT. In the future there will be a slight firming of prices as smelter acid suppliers attempt to improve their net backs by following the price rises posted by virgin producers. The estimates are that by 1990 the delivered price in the north central states will remain in the range of $35-40/MT on the basis of 1978 constant dollars. Exxon can expect a net back in the order of $10-15/MT.

Potential Market for Crandon's Sulfuric Acid

The markets of potential interest to Exxon's production of sulfuric acid can be identified as the North Central region. Although some potential for movement of acid to the Gulf area exists, it depends entirely upon the freight element from Evansville to the major consuming center in central Florida.

Two options are open to Exxon with regard to its sales of acid:

(1) Direct Sales - in the market review, a number of existing producers who may wish to cease production should a competitively priced byproduct be available.

(2) Merchant Sales - the retailing of sulfuric acid requires a substantial investment in both storage and distribution facilities if a major proportion of sales are made to smaller consumers. An attractive alternative to handling sales internally is to negotiate with a major sulfuric acid broker. The most obvious candidate is CIL, which in 1979 expects to move 1.3 million MT of sulfuric acid. By the early 1980s CIL expects to handle up to 1.7 million MTPY of sulfuric acid (excluding the output of Anaconda, with whom it is negotiating). In the longer term, they expect deliveries to reach 3 million MTPY.

The main advantages in dealing with a broker is the assured movement of the product and the saving in distribution costs. In the case of C-I-L, contracts are normally of 10 year duration plus a 1 year introduction period, during which acid production will be irregular, and a 2-3 year run down period at the end. The arrangement usually operates as follows:

(1) The acid producer invests in 6 weeks production storage equivalent, while C-I-L guarantees an equivalent storage, thereby assuring a 3 month total capacity.

(2) The producer, once the plant is operating normally, informs C-I-L of its expected production for the year and sales are agreed on the basis of ±10%. Any deviation from this is costed on the basis of existing spot prices, i.e., (a) if the producer exceeds the agreed figure, his net back on the surplus tonnage reflects the current market price; (b) if production is below the agreed level, the producer bears the cost of C-I-L's incursion into the spot market to maintain its sales obligations. The wider the range of supplies C-I-L deals with, the less severe will be the dislocation from any individual failing to meet his contracted volume.

3.5 MARKET FOR IRON PELLETS

The forecasts suggest that U.S. consumption of iron pellets will expand relatively rapidly during the forecast period. At present there is substantial excess capacity in the pellet industry in North America. The growth in consumption (plus exports) can be expected to take up much of this slack during the early 1980s. If all consumption were to be met by U.S. production there would be a need for additional capacity after 1985. However, when Canadian capacity is considered, there remains little need for new capacity (beyond that already planned) well into the second half of the 1980s. In addition, it is our view that there will be substantial supplies of pellets from outside North America competing for a share of the U.S. market throughout the 1980s.

The overall view of the market prospects, therefore, is that there will be a continuing downward pressure on pellet prices in the U.S. market for the next few years and probably continuing through most of the 1980s. Potential supply will be adequate to meet the growing demand such that producers will not be able to raise prices to the point at which high-cost new projects will be feasible.

We therefore believe that the current caution of the major iron ore companies concerning future investment is correct. Major new projects do not appear justified even though the U.S. is a competitive location for investment due to production costs and business climate.

Some further additions of U.S. pellet capacity can be expected in the second half of the 1980s to ensure that domestic producers do not lose their share of the home market, but it is expected that caution in investment and a generally easy supply of iron pellets will prevail at least into the second half of the 1980s.

The market for iron pellets is very large and, although the general market conditions may be unfavorable, it remains possible that individual and small operations may find conditions advantageous. Thus, while it may be difficult to finance and bring into production large increments of capacity such as a typical 4 million TPY unit, smaller operations may find marketing of their product easier and less depressing on prices. Similarly, particular qualities of pellets, or the need to recover only part of the capital cost of the total operation, could place an individual operator in a price or cost position untypical of the industry as a whole. Hence, while the overall assessment is that the market and price prospects for iron pellets are generally unfavorable, with prices being depressed below the full costs of new operations, and most likely falling in real terms over the next 10 years, further investigation would be required to ascertain whether this position applies to the product of any particular company or process.

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PYRITE PROCESSING STUDY
SUMMARY

The analysis has considered the balance of demand and supply in numerical terms only as far as 1990. Beyond that date it seems likely that consumption of steel in the U.S. will continue to increase at a slow rate, on an average of perhaps 1-1.5% per annum. There will, therefore, be an attendant demand for iron ore, increasing at approximately this rate to the year 2000. By the late 1980s it will be necessary for further major new production capacity for pellets to be established in the U.S. or Canada if the market demand for iron is not to be met from overseas projects. During this period prices can, therefore, be expected to move upwards in real terms to the point at which such major new investments become profitable. The precise timing or extent of such developments is not predictable at this stage because the market conditions of the late 1980s and 1990s will depend not only upon steel consumption in the U.S., but upon the developments in iron ore mining and processing outside the U.S. during the 1980s. If there are large quantities of surplus pellet production capacity in areas such as Latin America and Africa, then international market prices will be such that U.S. investment in pellet production will be delayed until the depressing impact of this surplus on pellet prices has passed. Alternatively, if many of the large overseas projects do not proceed as planned, the opportunities for investment in the U.S. may be better for the 1990s.

The overall assessment of the prospects for the iron pellet market, however, is that it will be difficult for a new producer to enter the U.S. market successfully in the foreseeable future and hope to recover the full cost of his capital plus a normal profit, unless there are special features of quality or production cost associated with his operations. The most promising area of investigation, assuming that the pellet product could be technically suitable, might be the production of the superior grade pellets required for direct reduction feed.

Prospects for Exxon's Pellets

Specifications

The byproduct iron oxide from Exxon's pyrite could be processed into 180,000 MTPY of pellets with the following composition:

Fe	65.1%	Pb	0.01%
Fe_2O_3	93.0	Zn	0.01
SiO_2	3.28	S	0.02
Al_2O_3	0.78	As	0.03
CaO	1.47	Cl	0.02
MgO	0.83	P	0.02
Mn	0.03	K	0.01
Cu	0.02	Na	0.01

Discussions with steel companies and other iron ore producers indicate that these would be considered good quality pellets. The iron content is quite high for U.S. pellets and other components seem to fall within the range of normal practice. This is confirmed in Table 13, where the analyses of most of the major types of U.S. pellets produced in 1977.

Table 13 : Analyses of U.S. Iron Ore Pellets

	Fe	P	SiO_2	Mn	Al_2O_3
Exxon	65.1	0.02	3.28	0.03	0.78
Empire-Cleve.-Cliffs	63.0	0.019	6.39	0.07	0.53
Marquette-Cleve.-Cliffs	63.4	0.051	5.00	0.07	0.76
Pioneer-Cleve.-Cliffs	59.6	0.057	7.87	0.34	2.81
Tilden-Cleve.-Cliffs	63.0	0.038	5.92	0.10	0.68
Groveland-Hanna	61.6	0.028	6.87	0.81	0.45
Aurora-Pick. Mather	62.5	0.015	6.00	0.20	0.37
Eveleth Taconite	64.6	0.013	5.32	0.09	0.37
Hibbing-Pick. Mather	64.4	0.002	5.02	0.08	0.15
Minntac-U.S. Steel	63.4	0.014	5.74	0.16	
Minorca-Inland Steel	65.8	0.014	3.62	0.13	0.20
National Steel	63.9	0.008	5.19	0.10	0.16
Reserve Mining	60.4	0.04	8.64	0.37	0.54
Bethlehem-Morgantown, PA	65.1	0.008	3.37	0.10	1.12
Pea Ridge, Miss.-Meramec	67.6	0.075	1.88	0.03	0.30
Pilot Knob, MO-Hanna	64.7	0.011	4.58	0.12	0.81

	CaO	MgO	S	Moist.*
Exxon	1.47	0.83	0.02	
Empire-Cleve.-Cliffs			0.001	2.31
Marquette-Cleve.-Cliffs			0.001	2.38
Pioneer-Cleve.-Cliffs			0.001	2.06
Tilden-Cleve. Cliffs			0.001	2.68
Groveland-Hanna	0.94	0.62	0.002	2.51
Aurora-Pick. Mather	0.44	0.44	0.004	3.25
Eveleth Taconite	0.37	0.41	0.002	2.09
Minntac-U.S. Steel				2.59
Minorca-Inland Steel	0.50	0.45		
National Steel	0.23	0.37	0.003	2.47
Reserve Mining	0.42	0.65		2.95
Bethlehem-Morgantown, PA	0.31	1.90	0.008	-
Pea Ridge, Miss.-Meramec	0.24	0.16		0.15
Pilot Knob, MO-Hanna	0.10	0.09	0.003	2.07

*Note: On a dry basis, the analyses of Fe and other constituents would be proportionally higher, generally bringing Fe into the range of 64-66%.

Source: American Iron Ore Association.

The small output of Exxon's proposed facility makes it hard to imagine any problem in finding a market for the pellets as blast furnace feed. In 1978, the U.S. and Canada produced 122 million metric tons of iron ore and the supply of pellets to the U.S. steel industry amounted to 82 million metric tons. The destination of the majority of these pellets is to blast furnaces around the Great Lakes, to which Exxon's pellets would also have easy access. Under these circumstances, and also considering the good quality of the pellets, Exxon should have no difficulty shipping its 180,000 metric tons into the market at close to the prevailing market price. The customers could be any number of integrated steel companies situated on the Great Lakes or Midwestern river system.

Pellet Prices

The history of posted prices for iron ore pellets at lower Great Lake ports is shown in Table 14. It is understood that the posted price is sometimes just a starting point for negotiations between seller and buyer. Discounting has occurred during periods of especially slack markets or for low quality pellets. Nevertheless, the trend of posted prices probably can be taken as reasonably representative of prices of good quality pellets.

Table 14: Lake Superior Pellet Prices at Rail or Vessel Lower Lake Ports

Year	Date	Price per long ton unit
1962-69		$ .252
1970		.266
1971-72		.280
1973		.291
1974	1-1 to 3-25	.291
	3-25 to 4-26	.29884
	4-26 to 5-2	.31189
	5-2 to 6-24	.3550
	6-24 to 12-30	.40619
	12-30 to 1-1-75	.44559
1975	1-1 to 2-7	.44559
	2-7 to 7-9	.452
	7-9 to 1-1-76	.472
1976	1-1 to 109	.472
	1-9 to 8-16	.5045
	8-16 to 1-1-77	.531
1977	1-1 to 1-7	.531
	1-7 to 1-1-78	.555
1978	1-1 to 3-21	.555
	3-21 to 9-6	.584
	906 to 1-1-79	.609
1979	1-1 to 4-4	.609
	4-4	.655

Source: Cleveland Cliffs Iron Company

The long term outlook for pellet prices is not especially favorable, and we would not expect to see sustained "real" price increases in the foreseeable future. This is because of the probable existence of more than ample North American pellet capacity during much of the 1980s, and beyond that period because of the depressing effects of large new foreign iron ore developments.

The current posted pellet price, $.655/long ton unit, translates to $42/metric ton of Exxon's pellets. We think it would be a fair approximation to use this as the estimate for future prices in constant 1979 dollars.

3.6 PHOSPHORIC ACID & PHOSPHATE FERTILIZER

3.6.1 Phosphoric Acid

Phosphoric acid is the most important inorganic acid produced and consumed in the United States in terms of production value, and second to sulfuric acid in volume. The major end-use of phosphoric acids is in the production of phosphate fertilizers, which accounts for over 85% of total consumption. Other uses in order of significance are livestock and poultry feeds, building and water treatment, food and beverages, direct acid treatment of metals, and fire control.

Its importance to the U.S. phosphate industry is illustrated by the fact that it accounts for 60% of total U.S. phosphate rock production and 85% of domestic phosphate rock consumption.

For the purposes of this report it is proposed to examine the developments of 54% P_2O_5 wet process orthophosphoric acid, i.e., fertilizer grade acid as used in the production of diammonium phosphates.

The U.S. Phosphoric Acid Industry

In 1978, phosphoric acid was produced by 24 companies at 32 locations throughout the U.S. Capacity currently stands at 8,841,000 MTPY of P_2O_5, a 68% increase since 1967.

Phosphoric Acid Consumption

As stated, the phosphate fertilizer is the major user of phosphoric acid. In 1978 it is estimated that of total domestic use, the fertilizer industry accounted for 93% of wet process phosphoric acid (including up-grading into superphosphoric acid). Outside the fertilizer sector the second major consumer is the animal feed industry, which has an annual consumption of up to 338,000 metric tons of P_2O_5 for the production of dicalcium phosphates. Other uses of significance are in construction and water treatment.

Table 15 - Total U.S. Phosphoric Acid Consumption
(1000 MT of P_2O_5)

Year	Triple Superphosphate (TSP)	Ammonium Phosphate (AP) Solid	Ammonium Phosphate (AP) Liquid	Direct Acid	Total
1965	1005	1182	200	19	2406
1970	1016	2337	472	37	3862
1971	1038	2693	529	31	4291
1972	1138	2998	581	29	4746
1973	1160	3111	585	35	4891
1974	1182	2810	615	29	4636
1975	1130	3250	467	27	4970
1976	1094	3664	631	23	5412
1977	1228	4301	663	30	6222
1978	1254	5378	736	30	7398

Source: USDC, SRI, TVA and CRU estimates.

The use of phosphoric acid falls into three major categories:

(1) Captive onsite use
(2) Merchant sales within the fertilizer industry
(3) Nonfertilizer demand

As 93% of the production is used in fertilizers the first two sectors are clearly the main channels. Therefore the decision was made to use the proposed phosphoric acid product for in-house use for making diammonium phosphate fertilizers.

To summarize, the demand for wet process acid is largely served by captive producers and the only market is the TSP/AP sector, which is largely self sufficient. Outside this sector are a wide range of smaller fragmented users who are currently served by existing phosphoric acid producers. The growth in the fertilizer acid market is not expected to generate a substantial incremental demand by these in the 1990s.

It is therefore recommended that Exxon's study in phosphoric acid be confined to its production as an intermediate for downstream production.

3.6.2 Phosphate Fertilizers

The use of phosphate fertilizers in North America is particularly well established - hence the recent relatively slow growth of consumption compared with developing countries. In 1977/78 North America accounted for about 18% of world demand, consuming just over 5 million metric tons of P_2O_5. Its market share is expected to remain unchanged throughout the 1980s, with an average annual growth rate of about 2% reaching nearly 7.5 million metric tons of P_2O_5 by 1990. Most of this demand will still be for triple superphosphate and diammonium phosphate, particularly as the importance of blending in fertilizer manufacture increases.

Supply comes entirely from domestic producers, and demand will probably be met by increased capacity utilization. It is also likely that diammonium phosphate capacity will expand in the long term, maintaining North America's position as the largest producer. North America is of prime importance as an exporter of concentrated products, and plays a dominant role in determining the nature of the world market itself, treating it as an extension of the home market. Growth in other regions will therefore focus on triple superphosphate and particularly diammonium phosphate, as North America's requirements are unlikely to change.

Outlook Beyond 1990

By the end of the century phosphate fertilizer consumption is forecast to reach 65.6 million metric tons of P_2O_5. This modest forecast is based upon the assumptions that:

(1) The residual value of phosphate fertilizers will prevent over-optimal applications.

(2) The failure of the developing world to achieve its potential. There is a considerable confusion between various consumption forecasts, some of which are based upon needed food production to supply forecast population levels. The forecasts presented in this report reflect actual usage, while forecasts based on need rather than achievement overstate fertilizer growth prospects.

Table 16: Development of Global Phosphate Fertilizer Consumption (1000 metric tons of P_2O_5)

	1980	1985	1990	1995	2000	Avg. Annual growth rate 1980-2000
Total	33,950	42,450	49,830	57,495	65,615	3.3%
West Europe	6,500	7,300	8,000	8,600	9,000	1.6
East Europe	9,800	13,000	15,500	17,000	18,750	3.3
Africa	1,150	1,600	2,050	2,555	3,215	5.3
North America	6,150	6,800	7,500	8,280	8,920	1.9
Latin America	2,500	3,750	4,750	6,060	7,730	5.8
Asia	6,500	8,600	10,500	13,400	16,300	4.7
Oceania	1,350	1,400	1,530	1,600	1,700	1.2

Source: CRU estimates

Supply/Demand Situation

An examination of the post 1980s supply/demand balance for phosphate fertilizers indicates that if production is to match the growth in demand, additional capacity will have to be commissioned by the mid 1980s. On the basis of all known plants and projects, current capacity forecasts reveal a potential short fall, starting by 1984-1985. It is too soon to draw many conclusions from such developments apart from the main conclusion. If a repeat of the chaos of the early-mid 1970s is to be avoided, up to 10,000,000 metric tons of additional capacity is required. This additional tonnage represents about 37,100 MTPD of P_2O_5 phosphate fertilizer units by 1990 (this excludes any replacement factor for existing units).

In the post 1990s, the assumption must be that given the available supplies of phosphate rock, there is no raw material constraint on the supply of phosphate fertilizers to the market. The only constraint may be the level of capital investment.

Diammonium Phosphate

The U.S. domestic market for diammonium phosphate will continue its upward trend for the remainder of the century. Consumption of diammonium phosphate is forecast to increase at an average annual growth rate of about 2% over the next 20 years. This projection is based upon the following considerations:

(1) A continued displacement of single superphosphate, and the absence of any growth in triple superphosphate usage. Indeed in the period 1990-2000, domestic usage of triple superphosphate will decline as the trend toward higher use of multi-nutrient fertilizers increases.

(2) The expansion of the dry bulk blend industry is one of the primary utilization channels for diammonium phosphate.

(3) The usage of diammonium phosphate as a direct application fertilizer is expected to increase marginally, particularly at the expense of triple superphosphate.

In terms of the market for Exxon's production of diammonium phosphate, in the physical sense, the Mid West corn belt market offers potential for any producer at competitive prices. At this juncture, however, it is of interest to consider how the Mid West market is currently served.

Production facilities in the region are limited. There are only three producers with a continued capacity of 770,000 metric tons per year. The balance between local production and consumption is all moved by the Gulf Coast producers.

Gulf production is moved by a combination of barge and rail. The inland waterways system allows Gulf producers the potential to move product to Minnesota, Wisconsin, Iowa, Indiana, Illinois and Ohio. Product is then off-loaded to terminals/railheads for subsequent transport inland. In addition to barge transported product, considerable qualities are moved directly by rail, particularly in the South Eastern region.

The marketing structure/channels of distribution in the Mid West corn belt area include all possible modes. However, for the purpose of this analysis four main channels are identified.

1. Co-operatives - there are at present three major primary producer/retailer co-operatives in the U.S. manufacturing diammonium phosphate:

   a) CF Industries formerly Central Farmers, is owned by 17 regional farm supply co-operatives in the U.S. and 2 in Canada. CF Industries, through its highly sophisticated distribution network, markets fertilizers in 42 states throughout the U.S. CF Industries has a particularly well developed distribution system in the Mid West.

   b) Farmland Industries is owned by 2200 locally owned member associations, and markets fertilizers in 15 Mid West states.

   c) Mississippi Chemicals is arranged as a co-operative, with 20,000 members, retailing mainly in the south east.

In addition to retailing their own brand products, the above co-operatives also move other producers' diammonium phosphate.

There are a number of smaller co-operatives which are not primary producers that operate on the distribution/bulk blending level. These include CENEX, Farm Bureau, Land and Lakes, Midland Farmers, Tennessee Farmers and Western Co-ops.

It is estimated that 40% of all fertilizers in the area are moved through the co-operative system.

2. Major Fertilizer Producers - outside of the co-operative producers, there are 18 producers with diammonium phosphate facilities.

3. Distribution Companies - operate retailing chains throughout the Mid West. The best example of this is Terra Chemicals/Riverside, which have combined into the major distribution company in the Mid West.

4. Bulk Blenders - while the major primary producers operate their own bulk blending facilities, there is a whole range of companies buying diammonium phosphate for use in the production of dry mixtures, dried bulk and bagged. It is estimated by TVA that there are over 7000 bulk blenders in operation in the U.S.

The main marketing centers in the corn belt are essentially the internal waterway terminals and major rail heads. For product moving northward from the Gulf, the first major distribution point is St. Louis, where product is transhipped by barge or rail to the Missouri and Kansas markets. Further north along the river system, product is transhipped at various points, Dubuque, Fort Madison and Minneapolis-St. Paul. In Illinois, product is moved as far north as Joliet. East along the Ohio River, product is moved as far as Cincinnati for distribution to Ohio consumers.

As Exxon has no distribution or marketing system for phosphate fertilizers, it is suggested that in the event of diammonium phosphate fertilizer production being economically feasible at either a Green Bay or Evansville location, the output be offered to the major co-operative groups and to bulk blenders for subsequent retailing. The major problem likely to be encountered will be the economics of moving phosphate rock to Green Bay or Evansville to be transformed into diammonium phosphate, and then to transport the finished fertilizer back along the internal system to the major distribution centers.

Green Bay

The marketing area for diammonium phosphates produced in Wisconsin is considered to be the following states:

Table 17 - Green Bay - Marketing Area - Consumption by State
(1,000 Metric Tons)

		1968	1970	1975	1976	1977	1978
Total		815	681	1224	1752	1960	1808
Wisconsin	(ENC)	123	64	111	150	151	135
Iowa	(WNC)	132	149	317	451	433	478
Illinois	(ENC)	100	178	272	440	565	460
Indiana	(ENC)	175	32	65	96	131	112
Ohio	(ENC)	103	44	84	120	136	127
Minnesota	(WNC)	93	117	266	318	328	308
Nebraska	(WNC)	84	87	84	138	172	135
Michigan	(ENC)	5	10	25	39	44	53

Source: TVA

In terms of the development of the market in the region, limited growth can be expected because of the already high level of P_2O_5 fertilization and the large proportion of cropped area. Nevertheless, some growth is expected. In 1978, the cropped area was some 5 million acres below maximum levels and there is potential for increased application rates in the west north central states. Incremental demand for the region, as a whole, is estimated to be in the order of 2% per year for the remainder of the decade. However, this is totally dependent upon the continued attractive cost/value ratio of fertilizers, and a strong international demand for U.S. food-stuffs. On the basis of 1.5-2% annual increase, demand for diammonium phosphate is expected to rise to 2.5-2.7 million metric tons by the year 2000.

Evansville

In the event of the plant being located at Evansville, the marketing area will encompass a number of states disclosed above. The additional states designated to be in an Evansville marketing area are Kentucky, where consumption of diammonium phosphate has increased five fold over the past 8 years to 91,000 MT in 1978 and Tennessee, where usage of a mere 6,000 MT in 1970 increased to peak of 75,000 MT in 1977 and stood at 69,000 MT in 1978.

The marketing potential of the Evansville plant is more favorable than of Green Bay in terms of its easy access to the major consuming area via the inland waterway system to the north west central states, notably Iowa, Illinois, and Minnesota which used 1.5 million MT in 1978. There seems to be limited scope for development of a direct application diammonium phosphate market to the east or south of Evansville, the market being dominated by NPK mixtures. However, as the majority of mixtures are diammonium phosphate based, some possible but as yet unquantified (except by a detailed study) market may exist at a bulk blender/mixer level.

Although there are no existing or proposed diammonium phosphate producers in either Kentucky or Tennessee, the major source of competitive suppliers will be from the large integrated Florida producers and major producers in Florida and Alabama. The Florida diammonium phosphate producers account for the majority of product consumed in the Mid West. The balance of supplies is produced by the Illinois and Iowa producers identified earlier.

Domestic Prices

In spite of significant improvements in the international market prices for diammonium phosphate, the domestic prices remain relatively depressed. This follows a 3 year period of relatively depressed prices at all levels. The development of diammonium phosphate prices is summarized in the following table and reveals the current price levels at approximately $30 per ton below those of 1975.

Table 18 - United States Domestic DAP Prices by Region*
(Average prices paid by farmers $ per short ton)

	1970	1973	1975	1976	1977	1978
Illinois	95	115	220	180	186	185
Indiana	96	115	215	180	186	185
Iowa	98	125	220	180	186	185
Kentucky	N/A	N/A	215	175	182	N/A
Minnesota	94	125	210	200	186	185
Nebraska	97	115	225	185	184	184
Ohio	90	115	215	170	186	185
Tennessee	N/A	N/A	226	200	182	N/A
Wisconsin	100	115	220	215	186	185
U.S. Average	95	119	216	177	187	187

*October 15th

Source: USDA

Future Domestic Prices

Although it is virtually impossible to accurately forecast prices over the next 20 years, it is our opinion that the trend in real terms will be upward. This is confirmed by a recent World Bank price forecast, which suggest that diammonium phosphate prices by 1990 are expected to reach $199.7 metric ton (1977$). The increase in price largely reflects the higher production costs of new plants commissioned to meet incremental demand.

On the basis of $220/metric ton F.O.B. Tampa (1980$) price by 1990, it is the opinion that the Green Bay and Evansville locations may be competitive on the basis of delivered prices in the Mid West estimated at between $250-260 per short ton (1980$).

Conclusions

Undoubtedly the U.S. domestic market for diammonium phosphate will continue its upward trend for the remainder of the century. Consumption of diammonium phosphate is forecast to increase at an average annual growth rate of about 2% over the next 20 years.

In terms of the market for Exxon's proposed production of diammonium phosphate, in the physical sense the Mid West corn belt market offers potential for any producer, but at competitive prices.

Availability of Raw Materials

Phosphate Rock & Anhydrous Ammonia

Both materials will be in ample supply through 2000.

3.7 MARKET FOR GYPSUM

3.7.1 Introduction

Gypsum is a name loosely applied to several different forms of calcium sulfate, including the minerals selenite ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$), and calcined gypsum ($CaSO_4 \cdot 1/2H_2O$) which is produced by heating selenite at about 350°F for over an hour. Technically, gypsum refers to the hydrated mineral, $CaSO_4 \cdot 2H_2O$, which occurs naturally in very large deposits all over the world and is mined at extremely low cost to produce the great majority of gypsum products. Because of its widespread abundance and low cost, gypsum is usually not transported very far to market.

Large quantities of byproduct gypsum result from various chemical processes, most notably the production of phosphoric acid. Without reprocessing, this material is unsuitable for most gypsum markets because of its chemical and physical characteristics. As the cost of reprocessing is high compared to the cost of natural gypsum, almost all byproduct gypsum is dumped, except for a small amount that can be used directly in agriculture. The notable exception to this practice is Japan, which is one of the few countries without adequate reserves of natural gypsum. The Japanese have been the leading nation utilizing byproduct gypsum as otherwise they would have to rely largely on imports transported long distances at escalating costs.

3.7.2 Gypsum Markets & Consumption Trends

The most important market for gypsum is as a building material, for which calcined gypsum is used in wallboard or as plaster. These calcined gypsum markets usually account for over two-thirds of total U.S. gypsum markets. In 1978, 14.4 million metric tons were used for board products, building and industrial plaster.

Crude gypsum is used in Portland cement to retard the setting of the concrete. This market utilized 3.6 million metric tons of uncalcined gypsum in 1978. In the same year 1.2 million metric tons, including both natural and byproduct gypsum, were used in agriculture to neutralize soils and to provide sulfur.

Other markets for gypsum are very small (127,000 metric tons in 1978). Ground white gypsum may be used as a filler in paint and paper and in toothpaste, yeast culture, face powder, varnish and rubber. Gypsum is sometimes added to oilwell drilling fluids to increase the calcium ion concentration, and small quantities of gypsum or anhydrite may be introduced into glass batches as a refining agent for bottle glass.

Table 19 shows the history of U.S. gypsum consumption since 1965. While the average long-term growth of total gypsum consumption has been slightly over 2% per year, the trend is dominated by the cyclical pattern of construction markets. However, within the building applications there has been a relatively strong (though cyclical) uptrend in wallboard which is somewhat masked in the figures by a downtrend in the use of conventional plaster.

The USBM projects that the trend growth rate of U.S. gypsum consumption will be about 2% per year to the end of the century. CRU has not done an independent analysis of future gypsum consumption growth because with any reasonable assumption about such growth there should be ample reserves of low cost natural gypsum to supply the market. Therefore, we believe that the high cost of reprocessing byproduct gypsum will rule out its use in most gypsum applications, or to be more exact in all except agricultural where it is used today in modest quantities without reprocessing.

Table 19: U.S. Gypsum Consumption by End-Use 1965-1978
(thousand metric tons)

	Building & Industrial Plasters*	Cement Retarder	Agriculture	Other	Total
1965	10,444	2,859	1,233	60	14,595
1966	9,147	3,058	1,125	73	13,404
1967	8,726	2,861	1,161	70	12,818
1968	9,696	3,119	1,259	98	14,172
1969	10,101	3,142	998	106	14,347
1970	9,137	3,046	730	88	13,001
1971	11,148	3,071	1,019	102	15,341
1972	12,896	3,559	1,039	112	17,607
1973	13,531	3,762	1,318	106	18,717
1974	11,647	3,681	1,516	112	16,955
1975	9,690	2,942	1,344	161	14,138
1976	11,469	3,099	1,555	221	16,344
1977	13,514	3,762	1,300	162	18,738
1978	14,443	3,565	1,236	127	19,372
Average % growth rate 1965-78 (trend)**	3.0%	1.6%	1.9%	8.1%	2.6%

Note: *Includes wallboard and other prefabricated products
**Growth rate of least squares trend line
Source: USBM

3.7.3 Agricultural Market

As was shown in Table 19, over 1 million tpa of gypsum is used in agriculture in the U.S. In 1978, approximately 46% of the material for this market was byproduct gypsum from phosphoric acid plants.

In agriculture, gypsum performs as a soil conditioner, provides a source of available calcium and sulfate and helps retain organic nitrogen in the soil. It is used in areas where soils are deficient in sulfur, and can serve as a "land plaster" to help reclaim land that has been inundated by seawater or over irrigated. Gypsum is applied to certain vegetable crops (especially potatoes and peanuts) where it enhances the fixing of nitrogen underground.

Because of the nature of its land, crops and irrigation practices, California is by far the largest market for agricultural gypsum. As shown in Table 20, the Pacific region accounted for 63% of the U.S. agricultural market in 1978. In California the major applications are for cotton and potato crops. The south atlantic states are the only other large consuming region, representing another 27% of the market. Here the main uses are for peanuts, other vegetables and cotton. The regions closest to Wisconsin use relatively insignificant amounts of agricultural gypsum.

Table 20: Gypsum Used for Agriculture in the U.S., 1978
(1000 metric tons)

Region	Quantity
New England	0.8
Middle Atlantic	13.0
E. North Central	14.3
W. North Central	20.9
South Atlantic	333.9
E. South Central	8.1
W. South Central	11.5
Mountain	55.1
Pacific	775.8
Exports	3.0
Total	1236.3

3.7.4 Gypsum Price History

Crude gypsum is a very low value product. In 1978, the USBM reported an average price of $6.83/MT (F.O.B. mine). Much value is added thereafter by calcining, production of prefabricated products, and transportation. In 1978, the average value of calcined gypsum was $25.57/MT (F.O.B. plant).

Table 21 shows the history of average crude gypsum prices as reported by the USBM. While the actual dollar price has increased over the period shown, the price in constant dollars has declined substantially since the 1950s, and in 1978 the price just managed to recover, in constant dollar terms, to what it was in 1970.

The average value of byproduct gypsum sold, reported by the USBM at $8.86/MT in 1977, seems to be somewhat higher than that of crude natural gypsum. This perhaps reflects the fact that in one of the major market areas for byproduct gypsum, the Southeast, there are few nearby sources of natural gypsum.

Table 21: Crude Gypsum Prices, 1955-1978
(dollars per MT)

Year	Actual Price	Constant 1965 $ Price
1955	3.51	4.27
1960	4.00	4.29
1965	4.11	4.11
1970	4.10	3.34
1971	4.13	3.20
1972	4.33	3.22
1973	4.61	3.24
1974	4.86	3.11
1975	5.05	2.95
1976	5.51	3.06
1977	6.12	3.22
1978	6.83	3.34

3.7.5 Production History

In 1978, U.S. mine production of crude gypsum was 13.1 million metric tons, which was a new annual record, surpassing the previous record year of 1973 by 6%. In addition, 568,000 metric tons of byproduct gypsum were used in agriculture during the year.

Imports of crude gypsum supply a significant share of the U.S. market, almost all coming from Canada (primarily Nova Scotia) and Mexico. In 1978 imports were 7.2 million metric tons, 75.1% from Canada and 19.5% from Mexico. The Canadian gypsum supplies processing plants on the U.S. East Coast which is the only large consuming region of the U.S. without nearby gypsum deposits. Mexican gypsum is used mostly in California.

Table 22 shows the history of U.S. gypsum supply.

Table 22: U.S. Gypsum Supply, 1965-1978
(1000 metric tons)

Year	Mine Production	Byproduct Gypsum Used	Imports	Total
1965	9,102	NR	5,362	14,464
1966	8,752	NR	4,971	13,723
1967	8,521	NR	4,140	12,661
1968	9,088	NR	4,966	14,054
1969	8,964	NR	5,314	14,278
1970	8,660	NR	5,559	14,219
1971	9,451	NR	5,528	14,979
1972	11,184	253	7,002	18,439
1973	12,300	292	6,950	19,542
1974	10,885	420	6,735	18,040
1975	8,846	335	4,942	14,123
1976	10,868	520	5,653	17,041
1977	12,165	513	6,417	19,095
1978	13,065	568	7,216	20,849

Note: NR - not reported
Source: USBM

3.7.6 Major Producers & Locations

In 1977, crude gypsum was produced by 42 companies at 69 mines in 22 states. In order of mine output, the leading states were Michigan, Texas, California, Iowa, Nevada and Oklahoma which produced more than one million short tons each and together account for 70% of the total. Figure 6 shows the location of U.S. mines and calcining plants. The notable point is that Exxon's property is virtually surrounded by major sources of gypsum in Michigan, Iowa and Indiana. This is confirmed by the reported production in nearby states shown in Table 23.

Table 23: Crude Gypsum Mined by State, 1977
(1000 metric tons)

States	Quantity
Michigan	1,745
Iowa	1,445
Indiana, New York, Ohio, Virginia	1,349
Arkansas, Kansas, Louisiana	1,024

The leading gypsum mining companies are United States Gypsum Company (12 mines), National Gypsum Company and Georgia Pacific Corporation (6 mines each), Celotex Division of Jim Walter Corporation (4 mines), The Flintkote Company (3 mines) and H. M. Halloway Inc. (1 mine). These six companies produced 71% of total U.S. crude gypsum in 1977.

In order of total output, the leading individual mines are:

1. U.S. Gypsum's Plaster City mine in Imperial County, California.
2. National Gypsum's Tawas mine in Iosco County, Michigan.
3. U.S. Gypsum's Albaster mine in Iosco County, Michigan.
4. U.S. Gypsum's Shoals mine in Martin County, Indiana.
5. H. M. Holloway's Lost Hills mine in Kern County, California.
6. Pacific Coast Building Products' Las Vegas mine in Clark County, Nevada.
7. U.S. Gypsum's Southard mine in Blain County, Oklahoma.
8. U.S. Gypsum's Sweetwater mine in Nolan County, Texas.
9. National Gypsum's Shoals mine in Martin County, Indiana.
10. Georgia-Pacific's Acme mine in Hardeman County, Texas.

These 10 mines accounted for 45% of the total in 1977.

3.7.7 Reserves/Resources

Domestic and foreign resources and reserves of gypsum are enormous and seem adequate far into the indefinite future. World reserves are conservatively estimated by the United States Bureau of Mines (USBM) at 1.8 billion metric tons, of which the U.S. has 320 million metric tons.

In the U.S., the largest gypsum resources are centered near three main areas, the Great Lakes area, California and the Texas-Oklahoma area. In Michigan, a continuous belt of gypsum bearing rocks underlies parts of Kent, Iosco, Mackinac, Ionia, Saginaw, and Eaton counties. These resources of gypsum are practically inexhaustible. Also in the upper Mid West, there are large deposits in Iowa and Indiana. In Webster County, Iowa, an area of 70 square miles is underlain by gypsum beds up to 30 feet thick.

Thus, there is no real possibility of exhaustion of natural gypsum supplies in the area of Exxon's interest.

3.7.8 Byproduct Gypsum

Byproduct gypsum is obtained mainly in the production of wet process phosphoric acid, but also in the production of hydrfluoric acid and certain other chemicals. Impure byproduct gypsum also results from the currently favored process for limestone scrubbing of SO_2 from power plant stack gases. If existing and/or future coal fired power plants are required to install scrubbers, large quantities of waste gypsum would result, almost all of which would be dumped.

In the most common phosphoric acid process, 4 to 5 metric tons of byproduct gypsum are produced for each metric ton of P_2O_5. This means that over 30 million metric tons of byproduct gypsum are produced each year, much more than the total U.S. consumption of natural gypsum. Except for the 500,000-600,000 metric tons of byproduct gypsum used in agriculture, all of this material is deposited in gypsum ponds.

There are many characteristics of byproduct gypsum that make it unsuitable for use in the main outlets for natural gypsum at a competitive price. The chief disadvantages are: (1) impurities such as fluorine, residual phosphoric or sulfuric acid, uranium, radium (raising fears of radioactivity from wallboard) and many others depending on the phosphate rock feedstock; and (2) the morphology of the crystals. In competition with abundant, low cost natural gypsum it has not been economically feasible in the U.S. to process byproduct into a more usable product. In the future the lack of land for waste gypsum disposal plus environmental pressures may force alternative disposition of this material.

Most of the byproduct gypsum used in agriculture is sold in California by Occidental Petroleum Corporation, Allied Chemical Corporation, Valley Nitrogen Producers Inc., and California Industrial Minerals Company. Sales of byproduct gypsum in other states are reported by Occidental Petroleum in Florida, Miles Laboratories in Indiana, Texasgulf in North Carolina, and Allied Chemical in West Virginia.

3.8 CONCLUSIONS

The results of our research, as reported above, clearly suggest that the prospects for sale of Exxon's byproduct gypsum would be very poor. Exxon's material, produced in a geographic region with virtually unlimited sources of natural gypsum, would be unusable for any but agricultural applications without further processing. Judging by the absence of such processing elsewhere, there is little chance that the value added in upgrading the gypsum would equal the processing cost.

This leaves agriculture as the only potential market for Exxon's gypsum, but the closest region with significant agricultural consumption is the South Atlantic, which is surely out of range of a Great Lakes plant but perhaps within the realm of possibility from a lower Ohio River site. In any event, we do not think that sales, even to the South Atlantic region, could be more than several tens of thousands of metric tons, which would hardly make a dent in the 2,400,000 MTPY available.

4. TRANSPORATION

The transportation report for this study was prepared by Jones, Bardelmeier and Company Ltd., Nassau, Bahamas, from which a summary was prepared for the Phase I report. A complete copy of the JBC report is available in the Appendix material.

The purpose of the transportation report is to provide transportation and intermodal cargo handling rates for the commodities used in the processing of the products to be produced from Crandon pyrite concentrates. The commodities and the annual volumes have been mentioned in the introduction and there is no need to repeat here.

Conclusions

The transport of pyrite concentrate from Crandon, Wisconsin to the process centers at either Green Bay, Wisconsin or Evansville, Indiana can be most economically handled by railroad. The same applies to Copperhill, Tennessee; therefore shipment interruptions due to winter water navigation problems are not a factor.

The most economical transport mode to and from Green Bay for the other commodities is via Lake Michigan, except anhydrous ammonia which is by rail.

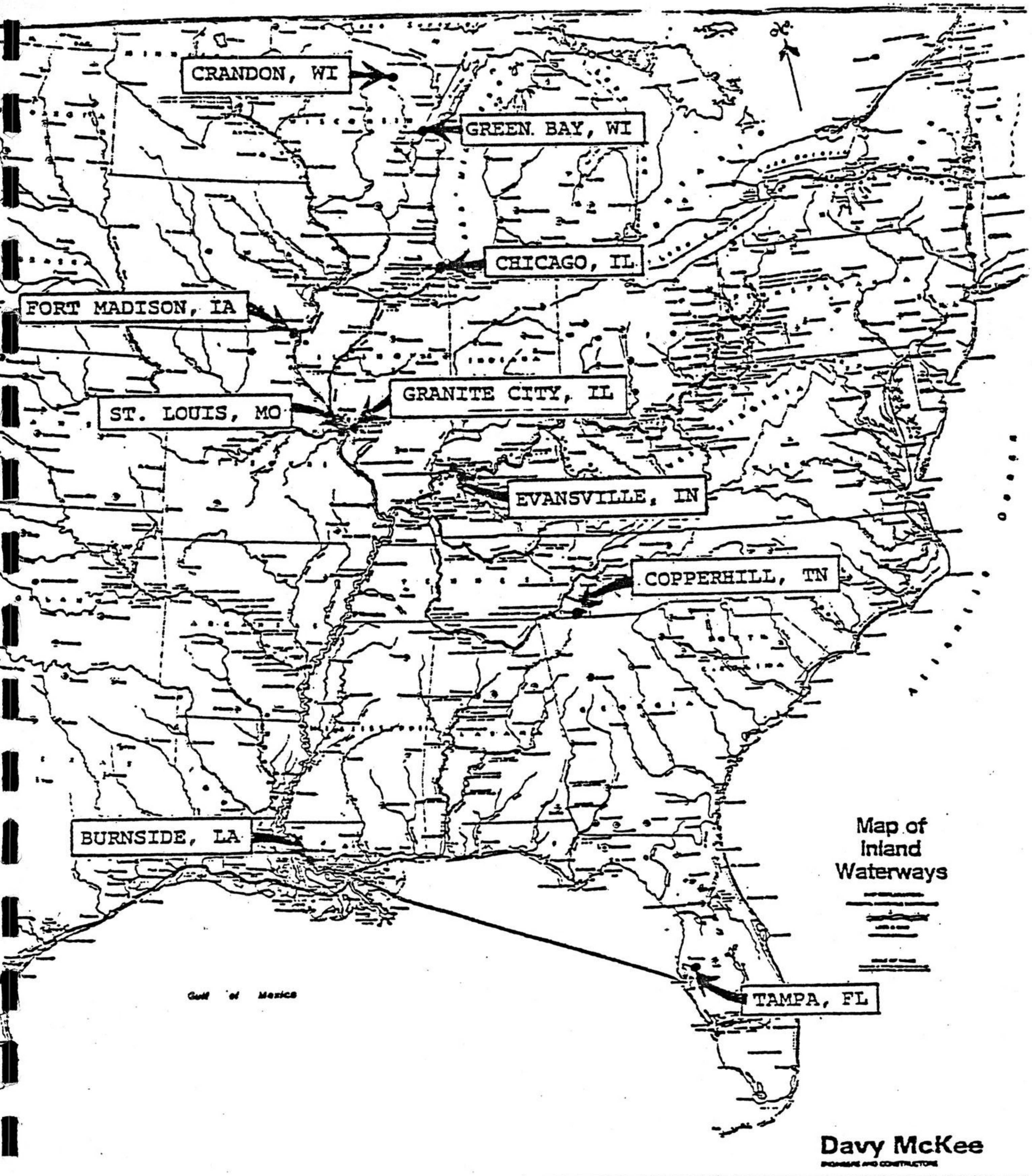
With regard to the Evansville process center, the most economic mode of transportation for all commodities is via barge and the Ohio River. The unfortunate situation is that Green Bay and the Lakes suffer from freeze-ups for approximately four (4) months in the winter time and rail transportation must be used during those periods. Evansville has the same problem, but only for two (2) months out of the calendar year.

The following tabulation summarizes the lowest cost transportation rates developed for each of the seven commodities between the Crandon mine, the two processing centers, selected marketing areas and the raw material sources. Rates are in U.S. dollars per metric ton F.O.B. destination effective mid 1979 and escalated to mid 1985 levels by using an intermodal rate forecasting developed by the Consulting Center. This intermodal rate assumes a continuation of recent trends regarding rate increases. It is tied to Chase Econometrics July 1979 long term Macro Economic Forecast.

Map 1 indicates the proposed process center(s), markets and supply sources.

SUMMARY OF ESTIMATED OPTIMUM TRANSPORTATION RATES

Schedule No.	Commodity	Origin	Destination	Rate US $/MT Mid '79	Rate US $/MT Mid '85	Mode
1	Pyrite	Crandon	Green Bay	11.44	16.80	Rail
2			Evansville	24.43	36.14	Rail
3			Copperhill	31.72	46.58	Rail
4			White Pine	15.50	22.18	Road
5	Iron Pellets	Evansville	Granite City	5.56	8.22	River
6			Chicago	10.73	15.74	River
7			Pittsburgh	11.19	16.42	River
8		Green Bay	Granite City	11.63	17.11	Lake/River
9			Chicago	3.38	4.96	Lake
10			Pittsburgh	15.94	23.53	Lake/Rail
11	Sulfur	Evansville	Chicago	7.43	10.90	River
12			E. St. Louis	3.31	5.15	River
13		Green Bay	Chicago	5.00	7.35	Lake
14	Sulfuric Acid	Evansville	Chicago	11.16	16.38	River
15			E. St. Louis	6.09	8.94	River
16			Burnside	14.59	21.43	River
17		Green Bay	Chicago	6.50	9.69	Lake
18			E. St. Louis	19.86	29.22	Rail
19			Burnside	26.64	39.23	Rail
20	DAP	Evansville	Ft. Madison	5.37	7.88	River
21			Omaha	12.79	18.78	River
22			Minneapolis	9.39	13.80	River
23		Green Bay	Ft. Madison	10.10	14.80	Lake/River
24			Omaha	15.81	24.19	Lake/River
25			Minneapolis	14.29	19.57	Rail
26	Phosphate Rock	Tampa	Evansville	12.16	17.82	Ocean/River
27			Green Bay	15.08	22.10	Ocean/Lake
28		Pocatello	Evansville	42.32	57.96	Rail/River
29			Green Bay	43.29	59.28	Rail
30		Morocco	Evansville	19.04	28.98	Ocean/River
31			Green Bay	16.13	23.67	Ocean/Lake
32	Anhydrous Ammonia	St. Louis	Evansville	14.85	21.05	River
33			Green Bay	26.50	38.94	Rail
34		Terre Haute	Evansville	13.04	19.16	Rail
35			Green Bay	23.65	34.75	Rail



Map of Inland Waterways

Davy McKee
ENGINEERS AND CONSTRUCTORS

MAP NO. 1

5. PROCESS SELECTION & TECHNOLOGY

5.1 PROCESS SELECTION

The two major marketable sulfur-bearing commodities produced from pyrite, elemental sulfur and sulfuric acid, have both well defined and proven technologies. The iron portion has also well established processing routes for its commercial preparation.

While the actual behavior of the Crandon's fine pyrite concentrate under storage and handling is not known, no insurmountable problems would be expected. For the purpose of this study it is assumed that a partially dried pyrite (about 12-16% moisture) and partially agglomerated by tumbling will have a safe and acceptable handling characteristics.

The commercial route for the production of sulfuric acid from pyrite comprises two stages: sulfur dioxide generation and its conversion into sulfuric acid. It is proposed to roast the pyrite in a fluidized bed reactor with partially dry feed, as indicated above. Some sintering and large dust carryover are expected, but both are within current commercial practice.

As indicated in the market study, the processing of sulfuric acid into ammonium fertilizers, via phosphoric acid, is suggested for continuity into an overall process concept.

For the production of high purity iron oxide and recovery of nonferrous and precious metals, there is only one commercial process applicable to fine pyrite with the Crandon composition; the Kowa Seiko process.

In order to perform economic evaluations of the possible alternatives available, the block flow diagrams in Figures 1, 2 and 3 have been selected.

Capital and operating cost estimates were prepared for the following processing units:

5.1.1 Pyrite handling and preparation
5.1.2 Roasting in turbulent bed reactors
5.1.3 Sulfuric acid manufacture, double catalysis
5.1.4 Phosphoric acid manufacture, Prayon method
5.1.5 Diammonium phosphate manufacture
5.1.6 Production of clean iron oxide pellets by the Kowa Seiko process
5.1.7 Recovery of nonferrous metals sludges

As a possible alternate, the breakdown of pyrite into elemental sulfur and iron residue is technically possible. There is only one facility (Kokkola, Finland) producing sulfur from pyrite, and only for one half of the sulfur content. Nevertheless, in order to produce a preliminary evaluation for this potential processing route, the overall process block diagram as shown in Figure 4 has been prepared. The same assumptions for pyrite handling behavior is taken.

The Allied (partial reduction - Claus) process is applied to the SO_2 conversion into elemental sulfur. It is assumed that the residual cinder is amenable to treatment for iron and nonferrous recoveries as in the former case.

Capital and operating cost estimates were prepared for the following alternate processing units (Figure 4):

5.1.8 Pyrite handling and preparation
5.1.9 Pyrite smelting - electric furnace
5.1.10 Matte granulation
5.1.11 Matte roasting - turbulent bed reactor
5.1.12 Partial reduction - natural gas
5.1.13 Claus unit
5.1.14 Sulfur cleaning

The iron cinder treatment with a Kowa Seiko type facility is assumed to be identical to the one shown in block flow diagram, Figure 3.

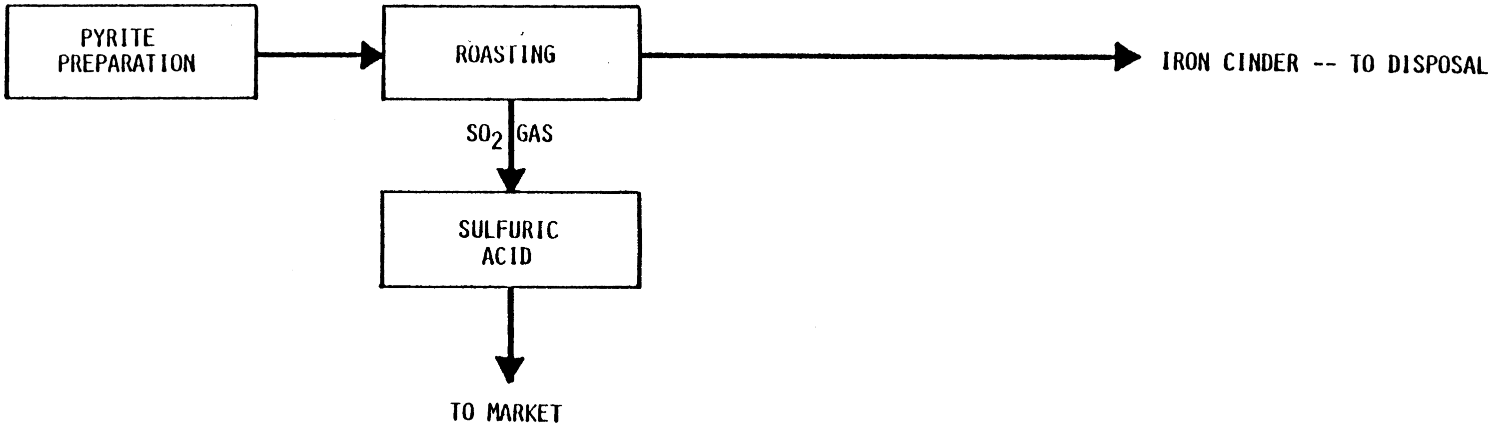
5.2 PROCESS DEFINITION

The purpose of this section is to discuss the technology available for processing Crandon's pyrite concentrate into the products defined by the marketing study. The process alternates are then technically evaluated and a selection is recommended for economical analysis.

A search of the state-of-the-art has been made, including the commercially proven processes, i.e., those that are or have been utilized on a commercial scale. It also includes those processes that have been operated in pilot scale, and the new trends that if not applied specifically to pyrite, have been, or are successfully used, in related areas of the minerals industry.

The search has been conducted along a pattern covering the following:

5.2.1 Pyrite handling and preparation
5.2.2 Direct elemental sulfur from pyrite
5.2.3 Sulfur dioxide from pyrite
5.2.4 Cinders reclamation (iron products)
5.2.5 Recovery of minor components (nonferrous metals)



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PROCESS BLOCK FLOW DIAGRAM

SULFURIC ACID ONLY. IRON CINDER TO DISPOSAL

FIGURE 1

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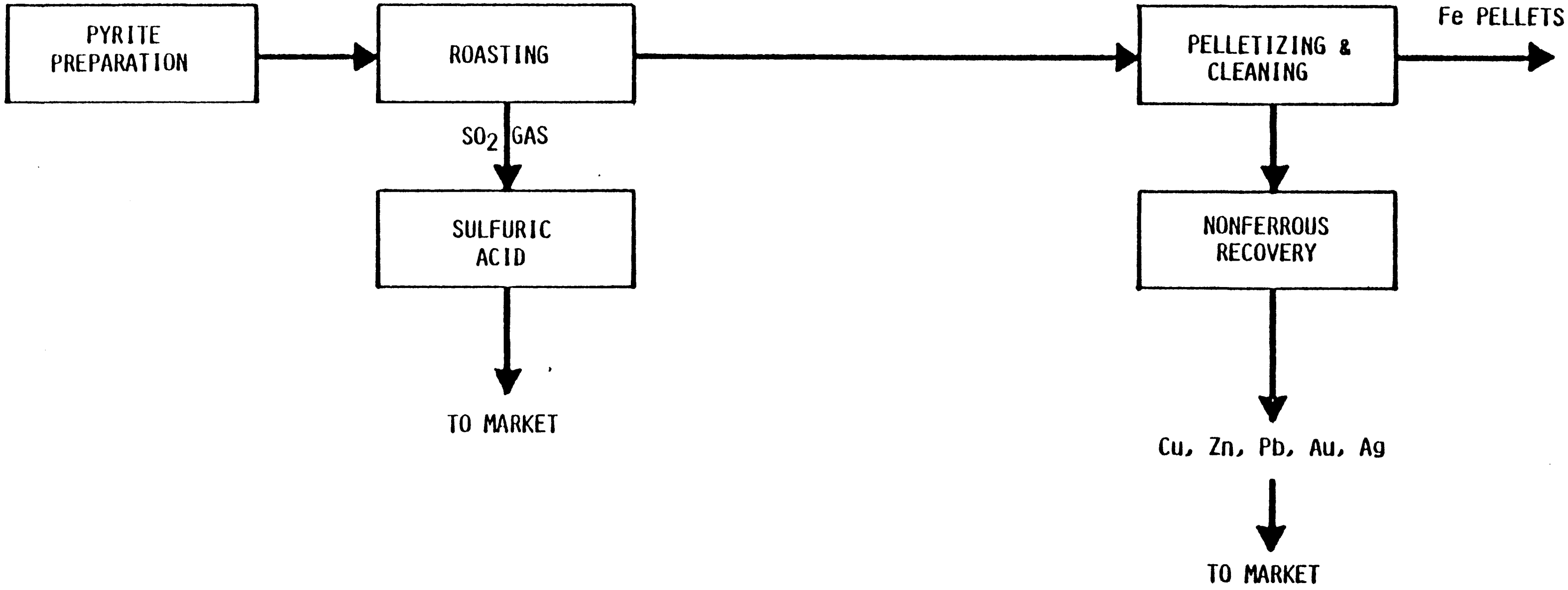
EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY



PROCESS BLOCK FLOW DIAGRAM

SULFURIC ACID, IRON PELLETS
AND NONFERROUS METAL RECOVERY

FIGURE 2

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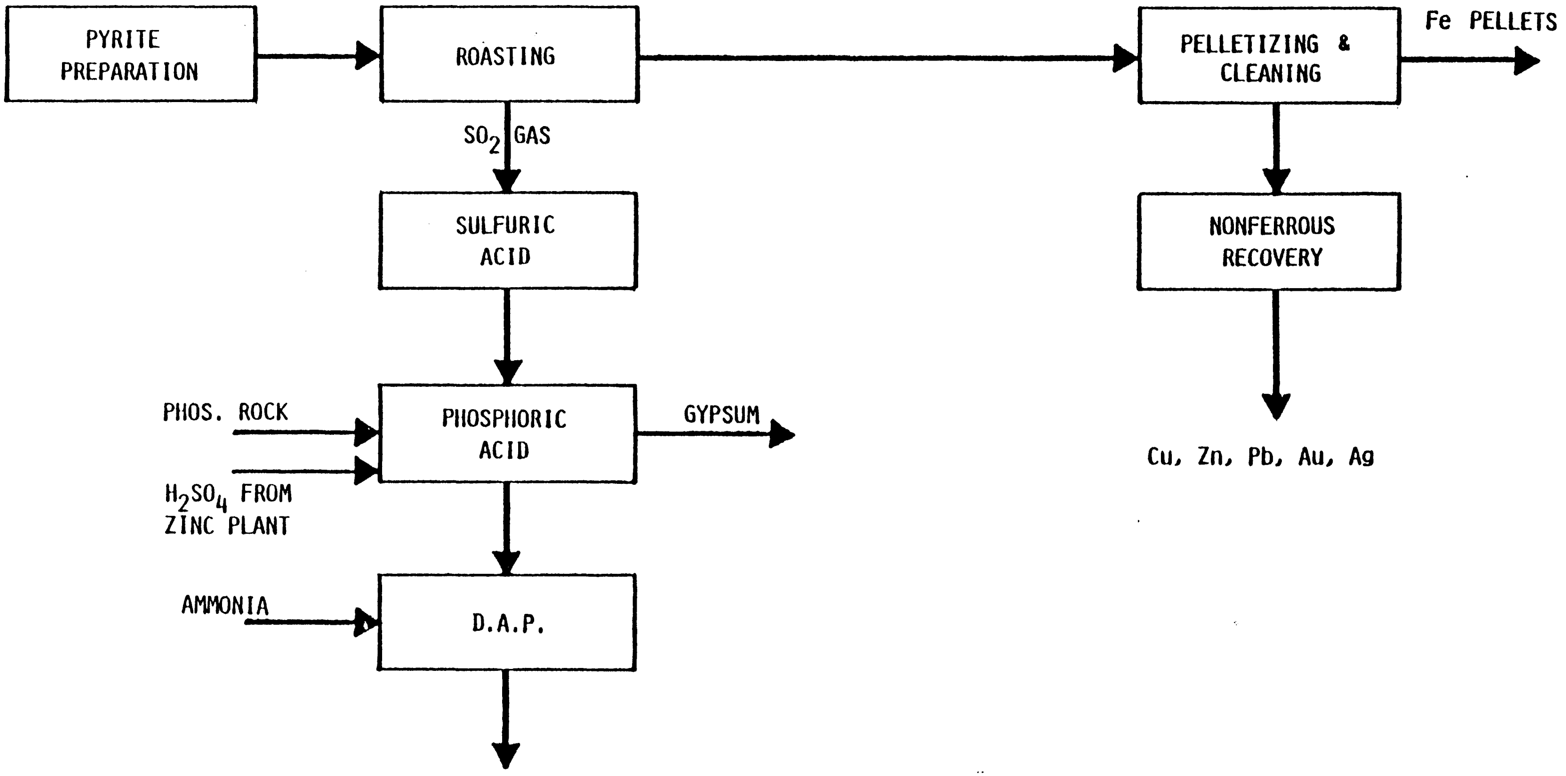
PYRITE PROCESSING STUDY



PROCESS BLOCK FLOW DIAGRAM
PELLET ROUTE
SULFURIC ACID, PHOSPHORIC ACID, D.A.P. AND IRON PELLETS
FIGURE # 3

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EXXON MINERALS COMPANY, U.S.A.

PYRITE PROCESSING STUDY

2489/3
June 1981

PYRITE PROCESSING STUDY
SUMMARY

The processing routes for converting SO_2 from pyrite into commercial products have been examined as follows:

5.2.6	Elemental sulfur from SO_2
5.2.7	Liquid SO_2
5.2.8	Sulfuric acid
5.2.9	Phosphoric acid
5.2.10	Diammonium phosphate

5.2.1 Pyrite Handling and preparation

Due to the extremely fine particle size (below 20 micron) of the Crandon's pyrite concentrate, and the high residual moisture (30%) in the filter cake, the transportation and handling of the pyrite is of some concern.

The possible routes for handling are:

- o-as a water slurry
- o partially dried
- o totally dried

A slurry system will minimize the risk of oxidation. However, increased transportation costs due to the excess water (50%), the requirement of special transportation containers, freezing conditions during winter and an adverse impact on the heat balance during processing, do not favor this approach.

A wet pyrite filter cake (30% moisture) is sticky and difficult to handle, it affects freight costs and will tend to form lumps. Partial dewatering directly on the filter by steam or compressed air displacement, followed by balling-tumbling agglomeration, will improve freight costs and handling problems. Any induration due to partial oxidation will improve its handling behavior.

Partial drying of the pyrite filter cake in a rotary, dryer followed by shipment in covered gondola cars is probably the most straight forward way of handling this product. Shipping moisture of 10-15% moisture should make a product that is handleable without dusting.

The technology for handling Crandon's pyrite is available, and for this study we have utilized a partially dried pyrite followed by tumbling agglomeration before discharging to low side gondola cars equipped with temporary covers for shipment.

5.2.2 Elemental Sulfur From Pyrite

5.2.2.1 Thermal Route

Heating pyrite above 700°C liberates about 50% of its sulfur in a vapor phase that may be recovered by condensation. The residue is an iron monosulfide.

$$FeS_2 + \text{Heat} = FeS + 1/2\ S_2$$

The reaction can be performed in a:

- Blast furnace - Orkla process
- Flash smelter - Outokumpu Oy
- Electric furnace - Pyror process
- Fluidized bed reactor

- The Orkla Process - has been operated commercially in Norway, Portugal and Spain. It was discontinued in 1962. Its principle was to mix pyrite lumps with coke and fluxes which are melted in a shaft furnace.

  In addition to the sulfur released thermally, part of the balance oxidizes to SO_2, and reacts with the coke to be reduced to elemental sulfur. Most of the iron, zinc and lead form a slag, and the residual iron and sulfur melts into a matte where copper, silver and gold are collected.

  The process requires an agglomerated feed, recovers about 80% of the sulfur and discards the iron.

- The Outokumpu Process - currently in operation at Kokkola, Finland, melts very fine pyrite in a flash furnace. Heat is provided by combustion of fuel oil. Half of the sulfur is recovered as elemental sulfur by condensation from the gases. The rest of the sulfur with all the iron and minor metallic components are collected in a molten matte. Outokumpu granulates the matte and re-roasts the matte to recover the SO_2 as sulfuric acid. The residue is leached for the recovery of its cobalt content.

  This process has been estimated as a probable alternate for elemental sulfur.

- The Pyror Process - operated only in pilot scale by Orkla-Grube, Norway, melted the pyrite in an electric furnace, vaporizing half of the sulfur and producing a matte similar to Outokumpu. The process is amenable to either coarse or fine feed.

The Pyror matte, after granulation, was dissolved in sulfuric acid with the production of H_2S and ferrous sulfate. The process is intended to produce electrolytic iron.

No commercial application.

- The Fluidized bed reactor - as proposed by Dorr Oliver and several researchers, provides the heat by combustion of liquid or gaseous fuels, as in the Outokumpu operation, but below the melting point of the residual monosulfide. Half of the sulfur is recovered from the gases, and the residue is amenable for further treatment. The idea has not been worked above the bench scale level and to date has not been applied commercially.
- Storage of FeS - The iron cinder or calcine produced by using any of the above processes is very fine in nature, difficult to handle and causes problems in disposal. The tendency to leach in contact with water may cause ground water problems. Also, under proper conditions it also can be pyrophoric.

5.2.2.2 Hydrometallurgical Route

Either the matte from Outokumpu or Pyror, or the residue from the partial desulfurization in a fluid bed reactor, are amenable to hydrometallurgical treatment by oxidation under pressure in an aqueous system, with the production of elemental sulfur and iron oxides and salts. The approach has been tested by Sherrit-Gordon in bench scale.

The same materials are amenable to atmospheric leach with sulfuric acid as performed by Pyror and proposed by others (McGauley-Hanna) with the generation of H_2S.

Hydrometallurgical treatment of copper concentrates (Anaconda), copper-nickel concentrates (Sherrit-Gordon) and copper-nickel matte (Amax) is currently performed on commercial scale. No known attempt has been made on pyrite above the bench scale or small pilot plant (1 ton per day) size. In any case, prior treatment of the pyrite is necessary.

5.2.2.3 Chlorine Route

The displacement of the sulfur from the pyrite by chlorine, with the formation of iron chlorides, has been thoroughly investigated by several independent companies and research establishments, such as Comstock & Westcott, Texasgulf, Outokumpu Oy, Mitterberg Kupferbergbau and Norsk Bergverk/Kisforedlingen. The iron chlorides are oxidized to iron oxides, and the chlorine is recycled. In spite of the promising thermochemistry of the system, it never went above the small pilot scale.

5.2.2.4 SO_2 Route

The Halvorsen process based on the reaction of SO_2 with iron sulfides to produce magnetite (Fe_3O_4) and elemental sulfur,[2] is interesting due to its exothermic nature.[3] Duisburger Kupferhutte built a pilot plant for a modified version of the process. Long retention time (15 hours) to complete the reaction caused the test work to be discontinued.

5.2.3 Sulfur Dioxide From Pyrite

The roasting of pyrite with air is the only process route for production of SO_2 used in commercial scale. It has been performed in rotary kilns, multiple hearth furnaces, fluidized bed reactors and cyclonic roasters. Due to its fine particle size, Crandon's pyrite is amenable to either the fluidized bed or the cyclonic roasting. Final recommendation requires a more detailed development of the pyrite handling concept.

This process was selected and estimated for capital and operating costs.

5.2.4 Cinder Reclamation (Iron Products)

In current commercial practice, after sulfur removal by roasting, the residue known as pyrite cinder consists of iron oxides with all the other elements originally present in the pyrite, except the bulk of the sulfur and part of the arsenic if present in the feed.

For the Crandon type of cinder, only chlorination offers a route for the removal of the impurities, leaving an iron residue acceptable for the iron and steel industry.

5.2.4.1 Chlorination-Leaching

The Henderson process (also known as the Ramen or Duisburger-Kupferhutte) consists of re-roasting the cinder mixed with sodium chloride at about 550°C, followed by percolation leaching of the cinder with the acid solution obtained by scrubbing the gases leaving the roaster. Since the leaching is performed by percolation, a coarse size material is required.

Several of the Henderson (DK) process disadvantages are listed below:

- The liquid effluent contains sodium and calcium chlorides. They are not amenable to economic recovery, and their disposal constitutes an environmental problem.
- Reagents (NaCl) are not recovered, and large amounts of sodium chloride are required.

- Zinc recovery is not complete enough, if present in substantial amounts, to produce a clean iron residue, and lead recovery requires a separate leach stage.

It is the general consensus in the industry that leaching operations for cinder cleaning shall be considered only if the metals recovered can economically justify the operation.

5.2.4.2 Chlorination-Volatilization

In an oxidizing atmosphere, either chlorine or chlorides, when reacting above 800°C, vaporize metals such as Cu, Zn, Pb, Au and Ag in a chloride form, meanwhile iron, alumina and silica remain as solid oxides.

The most important disadvantage for $CaCl_2$ as a source of chloride is its sensitivity to water vapor. This means that preferably fuel, free from hydrogen, should be used.

5.2.4.2.1 Chlorination with Calcium Chloride

5.2.4.2.1.1 Vuoksenniska Process - Combined cleaning and pelletization of the iron cinder. The fine iron oxide was agglomerated with calcium chloride. The green pellets were sintered in a shaft furnace and the volatile nonferrous chlorides recovered from the gases.

With a capacity of 90 metric tons per day, the plant operated for only two years.

5.2.4.2.1.2 Kowa Seiko Process - The maintenance problems associated with the Vuoksenniska process were overcome by the Kowa Seiko developments. Instead of a shaft furnace K-S utilizes rotary kilns. The recovery of the nonferrous metals is performed by dissolution in quench water instead of a dry route with electrostatic precipitation.

Presently the Kowa Seiko process has three commercial plants in operation in Japan. They produce iron pellets of blast furnace quality. The nonferrous and precious metals are recovered in the range of 80 to 90% and most of the calcium chloride is recycled into the process.

The Cities Service Company at Copperhill, Tennesse utilized the Kowa Seiko process until May of 1979 to produce new pellets for blast furnace use. The unit never performed well. It is labor and energy intensive and subject to high maintenance costs.

Even with the poor experience at Copperhill, the Japanese have been successful and it is believed that the problems associated with the Copperhill installation can be overcome by proper design and operation.

This process is selected and estimated for capital and operating costs.

5.2.4.2.2 Chlorination with Chlorine Gas

5.2.4.2.2.1 Lurgi-Duisburger Kupferhutte Process - Green pellets are treated in a shaft furnace with three identifiable zones; induration, chlorination and cooling, with separated gas flows for each zone.

The chlorination is performed with a chlorine-air mixture, and nonferrous and precious metals are removed as vapor chlorides.

The process, developed into a 100 ton per day pilot plant, indicates a favorable heat balance but is not yet commercial. The major disadvantage of the LDK process is the continuous feed stream of chlorine and the dispersal of liquid calcium chloride.

5.2.4.2.2.2 Fluo-Chlor Process - Several attempts have been made to achieve the chlorination volatilization without previous pelletization.

Sintef/Metallurgisk Institute in Norway proved the technology in laboratory experiments.

Montecatini-Edison operated a 50 ton per day pilot plant at Fellonica, Italy, with promising claims. This unit is currently shut down.

Outokumpu Oy in Finland accomplished (bench scale) the chlorination in a moving bed. Coarse-grained pyrite cinder is required.

5.2.5 Recovery of Minor Components (Nonferrous Metals)

Copper, lead, zinc, silver and gold removed as vapor chlorides during the iron cleaning process are collected in the quenching aqueous solution and recovered as sludges. A remaining chloride solution may be amenable to recycle. The technology is well established and has been in commercial use for many years. This process has been selected and estimated for capital and operating costs.

5.2.6 Elemental Sulfur From SO_2

A typical process to produce elemental sulfur from SO_2 rich gas is the partial reduction - Claus combination. Partial reduction may be performed by H_2, H_2-CO rich gas, or a light hydrocarbon. Part of the SO_2 is converted to elemental sulfur and part into H_2S. The Claus reaction ($2H_2S + SO_2 = 3S + 2H_2O$) completes the conversion.

This process is energy intensive and utilizes 32,140,000 Btu/MT of sulfur.

This process route has been estimated as an alternate solution.

Currently, two utility companies in the U.S. are producing sulfur or sulfuric acid from the weak SO_2 in the stack gases utilizing the Wellman-Lord/Allied (Claus) Process. Although this method could be used for the pyrite roaster gases of 10-14% SO_2 the cost would be excessive and the other methods discussed herein are more ammenable.

5.2.7 Liquid SO_2

Current commercial practice produces liquid SO_2 from concentrate gases (80% SO_2) by cooling and compression. For diluted gases, previous concentration is required. Current practice for the concentration is exemplified by the Asarco and Wellman-Lord processes.

Due to market limitation for liquid sulfur dioxide in the process center locations, capital cost and operating costs were not estimated.

5.2.8 Sulfuric Acid

The contact process, with vanadium pentoxide catalyst, dominates the market. Differences in details make the distinction for trade names and designs.

These processes are capable of producing good quality sulfuric acid and low SO_2 and SO_3 effluents. This process route was estimated for capital and operating costs.

5.2.9 Phosphoric Acid

Direct reaction of sulfuric acid with phosphate rock constitutes the basic route for the so called wet process for phosphoric acid. Complete designs are offered under other names, but differ in detail rather than in principle.

5.2.10 Diammonium Phosphate

Currently produced in granular form. The standard process for the production of the fertilizer grade involves the direct reaction of phosphoric acid with liquid or vapor ammonia, commonly known as DAP.

In this study, Item 4.9 and 4.10 are considered as a single process route and were estimated in that manner, both for capital and operating costs.

6. ECONOMICS

CAPITAL COSTS/OPERATING COSTS & REVENUES

INTRODUCTION

It has been previously determined from the preceding sections that the products to be investigated further for the capital costs, operating costs and revenues will be as follows:

- Sulfuric Acid
- Iron Pellets
- Diammonium Phosphate
- Nonferrous Metals & Precious Metals

The economics of the products indicated above are shown for four (4) cases:

(1) The Base Case

267,400 MTPY of Crandon pyrite
320,000 MTPY of sulfuric acid from the proposed zinc refinery

(2) Alternate Case "A"

1,094,800 MTPY of Crandon pyrite
320,000 MTPY of sulfuric acid from the proposed zinc refinery

(3) Alternate Case "B"

267,400 MTPY of Crandon pyrite
No zinc refinery sulfuric acid

(4) Alternate Case B-1

1,094,800 MTPY of Crandon pyrite
No zinc refinery sulfuric acid

6.1 CAPITAL COSTS

The capital cost estimates for all the cases are of ±25% accuracy. Refer to Figures 1, 2 and 3, process block flow diagrams which show the process routes from pyrite through to diammonium phosphate, including iron pellets and nonferrous metal recovery.

The capital estimates are based on the following:

- Process Description
- Equipment Lists
- Block Flow Diagrams
- Pictorial Flow Diagrams
- In-house information for recently built process facilities with pertinant corrections for differences in scope, uncertainty factors and price variations due to escalation.
- Developed flowsheets, with identification of major equipment, with telephone quotations and all with services evaluated by factors applied to the estimate for equipment.

The products associated with each process case are as follows:

- Figure 1 - Sulfuric acid only - pyrite cinder to waste
- Figure 2 - Sulfuric acid, iron pellets, nonferrous metal
- Figure 3 - Sulfuric acid, iron pellets, nonferrous metal reclamation and diammonium phosphate

The capital costs to produce the products indicated above are shown in Figures 5 through 8.

6.2 OPERATING COSTS

The criteria for the estimated operating costs as estimated by Davy McKee are as follows:

6.2.1 Process Materials

- Pyrite

  For in-house use, the pyrite is valued at no-cost plus transportation to destination. The freight rate from Crandon to Green Bay is \$11.44/MT, and \$24.43/MT to Evansville. A 15% moisture content in the pyrite material is assumed.

- Sulfuric Acid

  The sulfuric acid (400,000 MTPY) produced in the proposed pyrite roasting-acid facility is transferred at production costs. The sulfuric acid (320,000 MTPY) produced in the proposed zinc plant is charged out at \$15.00/MT.

- Phosphate Rock

  Dry phosphate rock of 68-70 BPL (32% P_2O_5) F.O.B. Tampa is \$27.50/MT. Freight rate Tampa to Green Bay is \$15.08/MT, and to Evansville is \$11.16/MT. The total cost to Green Bay destination is \$42.58/MT, and to Evansville, \$38.66/MT.

- Ammonia (Anhydrous)

  Delivered to plant site is \$138.00/MT.

- Defoamer

  The defoamer used in the phosphoric acid/DAP plant, delivered cost is \$0.65/kg.

- Grinding Balls

  Grinding balls in the Kowa Seiko process plant are a major cost item consuming approximately 350 grams/MT of pellets. The delivered cost of grinding balls is \$550/MT.

- Hydrated Lime

  In bags, delivered to plant site - \$60.00/MT.

- Scrap Iron

  Light type, delivered to plant site - \$110.00/MT.

- Limestone

  Fine ground, minus 1 millimeter (quarry residue), delivered to plant site - \$20.00/MT.

- Miscellaneous Operating Supplies

  15% of the direct labor cost is used.

- Calcium Chloride

  Anhydrous, 94-97% pure, flake or pellets, 80 pound bags, delivered to plant site - \$150.00 MT.

- Hydrogen Sulfide

  Liquid, 97.5% minimum, seller's tanks, delivered to plant site - \$0.22/kilogram.

6.2.2 Utilities

The utilities consumptions are based on energy balances, equipment sizing and experience.

- Electric Power

  The unit price utilized is $0.03/kWh.

- Fuel

  Rather than expressing the fuel requirements in weight or volume, we are using energy units. Each million kJ is $2.65, equivalent to $2.50/million Btu or thousand cubic feet of natural gas (1 kilo joule = 1.06 Btu).

- High Pressure Steam

  High pressure steam is generated in the roasting plant boiler and in an auxiliary boiler. This high pressure steam is charged out at $7.70/MT and is equivalent to $3.50/thousand pounds of steam.

- Low Pressure Steam

  Low pressure saturated steam is charged or credited at $6.60/MT equivalent to $3.00/thousand pounds.

- Water

  Make-up water including treatment, for the various process areas is charged out at $0.05 per cubic meter, equivalent to $0.19 per thousand gallons.

6.2.3 Direct Labor

- Direct labor costs are as follows:

Foreman	$16.00 per hour
Operator	$12.00 per hour
Laborer	$ 8.00 per hour

  These rates include all fringe benefits. One man-year is equivalent to 2080 man hours.

- Supervision, above the foreman level is estimated at 15% of the labor cost.

6.2.4 Maintenance

Maintenance costs are estimated on a percent of the individual plant capital cost, excluding offsites. The following percentages were used:

Pyrite handling and roasting	3.0%
Sulfuric acid plant	1.5%
DAP plant	5.0%
Iron pellets plant	5.0%

Total maintenance cost is split as follows:

Labor	30%
Materials	70%

6.2.5 Plant Overhead

Includes all personnel not involved directly in operation and maintenance activities, such as management, accounting, laboratory, etc., and its supplies. It is estimated at 80% of all labor, including operating and maintenance labor.

6.2.6 Indirect Overhead

Management expenses and local administrative cost for items such as travel, communications, entertainment, etc., are estimated at 5% of the total operating costs.

6.2.7 Fixed Cost

Fixed costs include insurance, taxes, depreciation and the cost of money. A 15 year plant life is used, and a 100% loan basis at 10% annual interest is assumed.

Insurance and taxes	3.00%	
Depreciation	6.67%	on total capital
Interest (average)	5.7%	

6.2.8 Plant Investment

The plant investment used for the operating costs includes a prorated distribution of the offsites capital cost as follows:

	BASE CASE 267,400 MTPY		ALTERNATE CASE A 1,094,800 MTPY	
	Capital $ Million	Offsites Distributed $ Million	Capital $ Million	Offsites Distributed $ Million
Sulfuric Acid	43.5	61.8	147.0	198.65
DAP	45.5	64.7	120.0	162.15
Iron Pellets	13.0	18.5	29.0	39.2
Offsites	43.0	-	104.0	-
TOTAL	145.0	145.0	400.0	400.0

Using these criteria we have determined the operating costs for the base case (267,400 MTPY) and for the Alternate Case A (1,094,800 MTPY). The operating costs are summarized for both Green Bay and Evansville on Summary Sheet 1. The operating costs do not include expected return on investment.

6.2.9 Working Capital

Working capital is estimated to be 25% of the total plant investment.

6.2.10 Pre-Operational Costs

Pre-operational costs are estimated at $3,000,000.

SUMMARY SHEET 1

CRANDON'S PYRITE PROCESSING

OPERATING COSTS SUMMARIZED

All figures in dollars per metric ton

	Raw Materials	Utilities	Payroll	Materials & Supplies	Capital	Total
Sulfuric Acid						
1) Green Bay	9.00	(1.67)	3.95	2.54	26.21	40.03
1) Evansville	19.21	(1.67)	3.95	2.54	26.21	50.24
2) Green Bay	8.70	(1.61)	2.84	2.16	19.67	31.76
2) Evansville	18.57	(1.61)	2.84	2.16	19.67	41.62
DAP						
1) Green Bay	127.20	5.72	7.93	4.73	19.51	165.10
1) Evansville	128.82	5.72	7.93	4.73	19.51	166.71
2) Green Bay	127.03	5.78	4.88	4.17	17.31	159.12
2) Evansville	132.03	5.73	4.88	4.17	17.31	164.12
3) Green Bay	140.15	5.72	13.25	4.60	19.32	183.05
3) Evansville	147.57	5.72	13.25	5.35	19.32	191.21
4) Green Bay	130.71	5.69	5.63	3.73	19.38	165.15
4) Evansville	137.77	5.69	5.63	3.73	19.38	172.20
Iron Pellets						
1) 180,000 MTPY	-	8.19	11.96	6.17	15.66	41.98
2) 718,000 MTPY	-	8.18	6.02	4.27	8.32	26.79
Sulfur						
1) Green Bay	29.75	21.12	13.22	11.90	75.77	151.76
1) Evansville	61.17	21.12	13.22	11.90	75.77	183.17
2) Green Bay	29.67	17.43	11.35	8.33	53.74	120.82
2) Evansville	60.86	17.43	11.35	8.33	53.74	151.71

1) Base Case; 267,400 metric ton pyrite per year with zinc refinery acid
2) Alternate Case A; 1,094,800 metric ton pyrite per year with zinc refinery acid
3) Alternate Case B; no zinc refinery sulfuric acid (400,000 MTPY H_2SO_4)
4) Alternate Case B1; no zinc refinery sulfuric acid (1,694,000 MTPY H_2SO_4)

6.3 REVENUES

It has been previously mentioned that no market exists for the Crandon pyrite concentrates, therefore, two (2) representative sites have been assumed where the concentrate could be shipped for further processing:

- Green Bay Wisconsin area
- Evansville, Indiana area

At the process center, the pyrite concentrate would be further processed to the following products (Figures 1, 2, 3 and 4) in both the base case and the alternate case:

- Sulfuric acid alone. Discard pyrite cinders to waste (Figure 1)
- Sulfuric acid, iron pellets and nonferrous metals residues, (Figure 2)
- Sulfuric acid, iron pellets, nonferrous metals residues, phosphoric acid and diammonium phosphate (Figure 3).
- Elemental sulfur and iron residue and nonferrous metal residues (Figure 4).

The products, so produced would be transported to the marketing areas at the following commodity values (1979 dollars):

Pyrite	2.00/MT F.O.B. Crandon, Wisconsin
Sulfuric Acid	15.00/MT (net back to Exxon) F.O.B. Process Center
Iron Pellets	42.00/MT F.O.B. Process Center
Diammonium Phosphate	220.00/MT F.O.B. Process Center
Sulfur	75.00/MT F.O.B. Process Center
Nonferrous Metal Residue	
Copper $0.52/lb	1140.00/MT F.O.B. Process Center
Lead $0.26/lb	575.00/MT F.O.B. Process Center
Zinc $0.20/lb	460.00/MT F.O.B. Process Center
Precious Metal Residues	
Gold @ 300.00/oz	8000.00/kg F.O.B. Process Center
Silver @ 7.50/oz	200.00/kg F.O.B. Process Center

The recent wild fluctuations in the prices of gold and silver make it difficult to determine the market price. The values used are as follows:

Copper	87¢/lb	
Lead	43¢/lb	60% of market
Zinc	33¢/lb	
Gold	\$375.00/oz	80% of market
Silver	\$9.38/oz	

It should be noted that the metals produced in the proposed nonferrous metals plant will be in the form of sludges that will require further processing to obtain a final saleable product. A complicated formula involving smelting charges, refining charges, penalty charges due to detrimental elements that may be in sludges and finally the obtainable recoveries of each metal.

6.3.1 Sulfuric Acid Alone (Figure 1)

In this process route, the pyrite would be roasted to eliminate the sulfur as a SO_2 gas that would feed a sulfuric acid plant. The pyrite cinder containing iron would be discarded to waste, which also means that the nonferrous metals and precious metals would be lost. A suitable disposal area for this material would have to be provided.

The losses to Exxon would be as follows:

	Base Case 267,400 MTPY Pyrite	Alternate Case A 1,094,000 MTPY Pyrite
Green Bay	(\$10,016,000)	(\$28,425,320)
Evansville	(\$14,100,000)	(\$45,094,280)

See Figures 11 and 12.

6.3.2 Sulfuric Acid, Iron Pellets and Nonferrous Metal Residues (Figure 2)

This process route uses pyrite roasting to produce sulfuric acid and pyrite cinder. The sulfuric acid would be marketed and the cinder further processed to produce iron pellets and the nonferrous and precious metals residues would be sold for reclaim.

The total revenues that would be recognized by this process route would be $17,258,975 including nonferrous and precious metals. Utilizing the production costs for the respective process centers, the loss to Exxon would be as follows:

	Base Case 267,400 MTPY Pryite	Alternate Case A 1,094,000 MTPY Pyrite
Green Bay, Wisconsin	($6,318,625)	($2,349,790)
Evansville, Indiana	($10,395,625)	($19,018,750)

These revenues include the reclamation of the nonferrous metal residues and precious metals at 60% and 80% of their market values. See Figures 13 and 14 for the total revenue picture for this product route.

6.3.3 Phosphoric Acid & Diammonium Phosphate, Sulfuric Acid, Iron Pellets, Nonferrous Metal Residues, - (Figure 3)

This product route is identical to the previous process route with the utilization of the sulfuric acid produced above (400,000 MTPY and 1,694,000 MTPY) plus 320,000 MTPY from the proposed electrolytic zinc plant. The 720,000 MTPY and 2,014,000 MTPY of sulfuric acid would be utilized to manufacture phosphoric acid and subsequently diammonium phosphate as the marketable product.

The cinder produced by roasting the pyrite would be processed further to produce iron pellets and for the reclamation of the nonferrous metals and precious metals.

The total revenues that will be recognized from this process route not including zinc refinery acid would be $134,898,975 and $391,150,750 respectively. The return before taxes would be as follows:

	Base Case 267,400 MTPY Pyrite	Alternate Case A 1,094,000 MTPY Pyrite
Green Bay, Wisconsin	$34,558,175	$121,778,890
Evansville, Indiana	$33,453,355	$113,919,890

The returns shown above consider the pre-development costs, the plant capital costs, working capital and operating costs. It does not include sales costs, research and development, cost of money, corporate overhead or profit. Therefore, we utilized Davy McKee's computer program that derives the discounted rate of return and present value profit. Results of the discounted cash flow studies are as follows:

	BASE CASE 562,000 MTPY DAP 180,000 MTPY IRON PELLETS	ALTERNATE CASE A 1,572,000 MTPY DAP 718,000 MTPY IRON PELLETS
Market Price	Indicated ROI	Indicated ROI
\$220.00/MT - DAP 42.00/MT - Iron Pellets \$262.00	2.51	5.32

The nonferrous and precious metal residues are handled as previously indicated. See Figures 15, 15-A1 through 15-D1 and 15-A2 through 15-D2 and which show the ROI for these product routes.

6.3.4 Sulfuric Acid, Iron Pellets, Nonferrous Metal Residues, Phosphoric Acid & Diammonium Phosphate (Figure 3)

This product route is identical to 6.3.3 except that the sulfuric acid from the proposed electrolytic zinc plant is eliminated.

There is a possibility that the zinc, copper and lead concentrates may be sold to existing operations eliminating the need for a zinc roasting and sulfuric acid facility. This in turn would reduce the availability of sulfuric acid for phosphoric acid and diammonium phosphate to 400,000 MTPY (B) and 1,694,000 MTPY (B-1) of H_2SO_4.

The phosphoric acid and diammonium phosphate facility and products would be reduced to the following:

	Sulfuric Acid MTPY	DAP Produced MTPY
Alternate Case B	400,000	313,000
Alternate Case B-1	1,694,000	1,322,228

The total revenues that will be recognized from this product route without the use of zinc refinery acid would be $80,118,975 for Alternate Case B, and 336,200,750 Alternate Case B-1. The return before taxes, sales expense, etc., would be as follows:

	Alternate Case B 400,000 MTPY Sulfuric Acid	Alternate Case B-1 1,694,000 MTPY Sulfuric Acid
Green Bay, Wisconsin	15,269,725	98,599,576
Evansville, Indiana	12,715,645	89,277,868

	ALTERNATE CASE B 313,000 MTPY DAP 180,000 MTPY IRON PELLETS	ALTERNATE CASE B-1 1,322,228 MTPY DAP 718,000 MTPY IRON PELLETS
Market Price	Indicated ROI	
$220.00/MT - DAP	(7.44%)	(2.81%)
42.00/MT - Iron Pellets		
$262.00		

See Computer Sheets, Figures 17, 17-A1 through 17-D2 for the apparent ROI.

Note that we have only computer read-outs on the Process Center at Green Bay, Wisconsin as there is no significant differences between the ROI at Green Bay and Evansville.

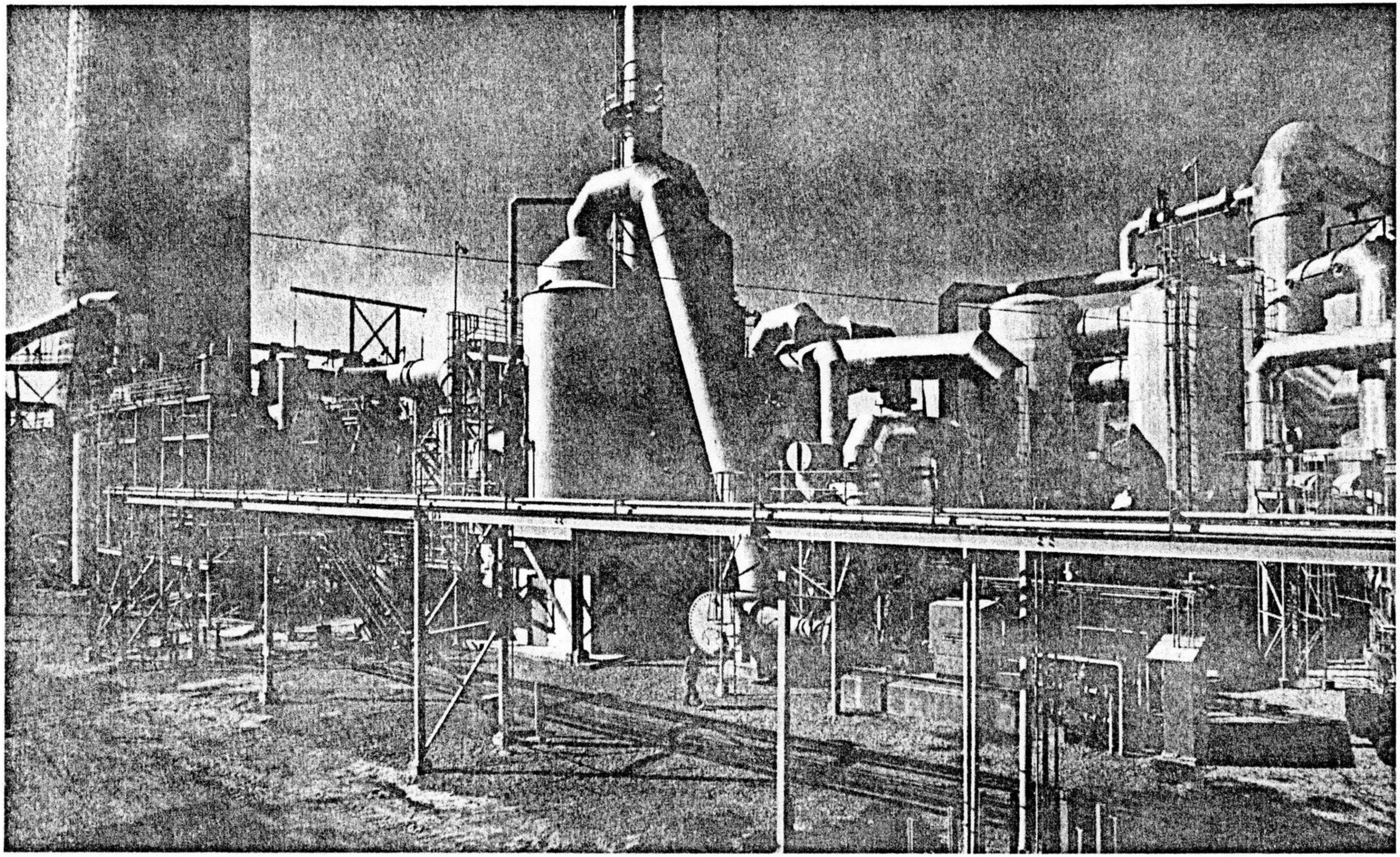
None of the process routes appear even marginally viable related to Exxon's normal rate of return (15%). The risks and large capital investments associated with this type project makes it a poor investment. In addition, the environmental problems associated with gypsum disposal from the phosphoric acid plant becomes a major factor.

GLOSSARY OF TERMS

APC	Air Pollution Control
B.P.L.	Bone Phosphate of Lime
CAAA	Clean Air Act Amendments
Calcine	Metal oxide after sulfur removal by roasting
C.I.L.	Canadian Industries Ltd.
Cinder	Pyrite product after sulfur removal by roasting
C.R.I.	Consolidated Research, Inc.
C. R. U.	Commodities Research Unit, Ltd.
DAP	Diammonium Phosphate
DK	Duisburger Kupferhutte
D.W.T.	Dry Weight Tons
EPA	Environmental Protection Agency
Fatal Acid	Involuntary Producers, Mainly Smelters
Fl-C	Fluo-Chlor
F.O.B.	Free on Board
Frasch Sulfur	Sulfur produced from natural deposits mined by melting underground and pumped to the surface
H_2SO_4	Sulfuric Acid
H/DK	Halverson/Duisburger Kupferhutte
Intermodal	From one method of transportation to another
J.B.C.	Jones, Bardelmeier & Co. Ltd.

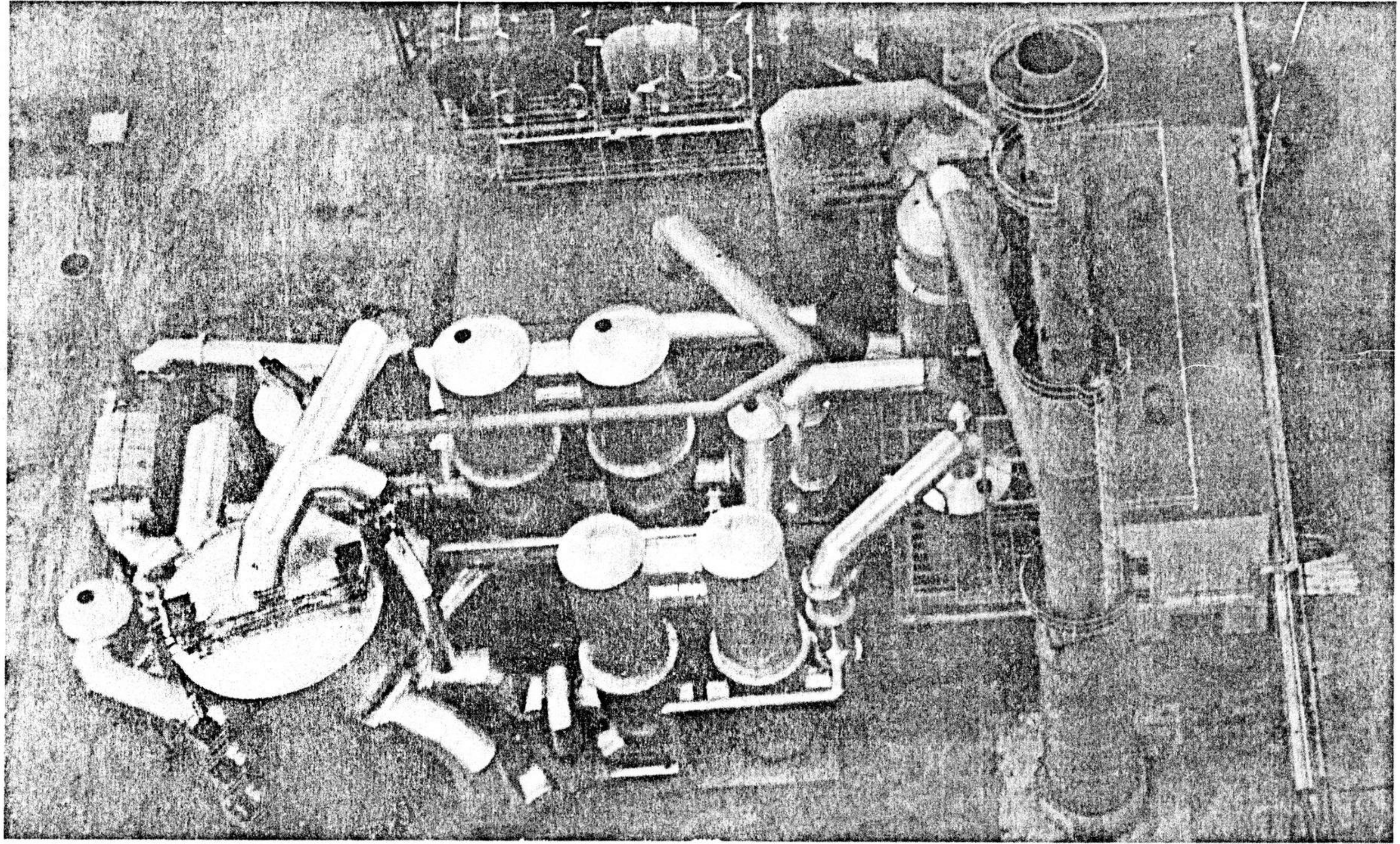
Kg	Kilograms
Kg/y	Kilograms per year
Kj(Kilojoule)	1.0 Btu
LDK	Lurgi-Duisburger Kupferhutte
L.T.U	Long Ton Unit
Matte	A crude mixture of metal sulfides formed in the smelting of sulfide ores
mcf	million cubic feet
Micron	1/1000 of a millimeter = .00004"
MM	Million
mm	millimeter
MT	Metric Tons (2200#)
MTPA	Metric Tons Per Annum (2200#)
MTPY	Metric Tons Per Year (2200#)
N	Nitrogen
Net Back	Commodity Price less Transportation
NPDES	National Pollutant Discharge Elimination System
P_2O_5	Phosphoric Acid
Phos Acid	Phosphoric Acid
Phos Rock	Phosphoric Rock
PSD	Prevention of Significant Deterioration
PSF	Pounds Per Square Foot
Slimes	A very fine material in slurry form

Smelter Acid	Sulfuric acid made from smelter gases
SO_2	Sulfur Dioxide
ST	Short Tons (2000#)
STPA	Short Tons Per Annum (2000#)
STPY	Short Tons Per Year (2000#)
TVA	Tennessee Valley Authority
U.S.B.M.	United States Bureau of Mines
U.S.D.A.	United States Department of Agriculture
U.S.D.C.	United States Department of Commerce
Virgin Acid	Sulfuric acid made from elemental sulfur



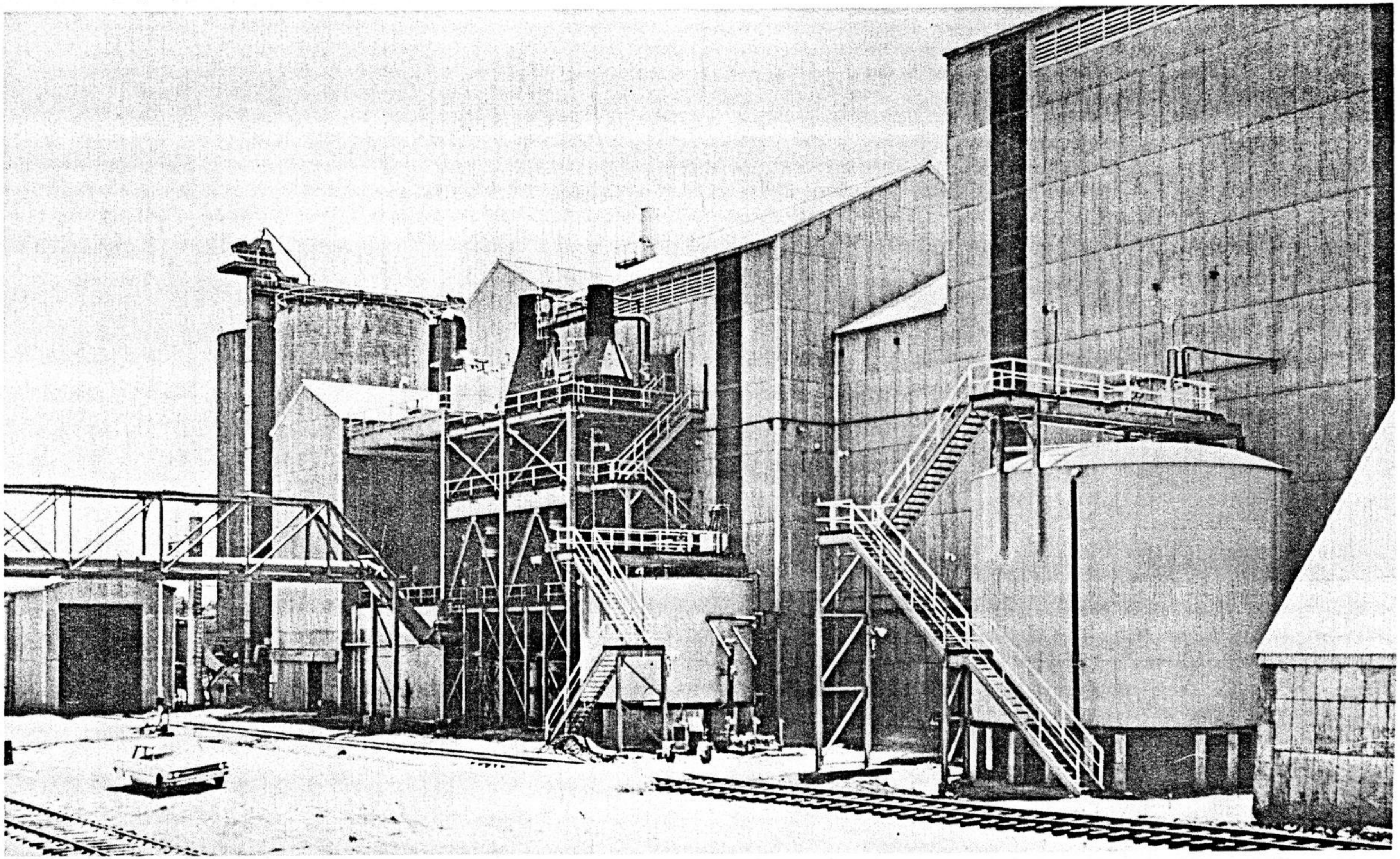
AMERICAN SMELTING & REFINING CO.
(ASARCO)

930 TPD METALLURGICAL SULFURIC ACID PLANT



THE ANACONDA CO.

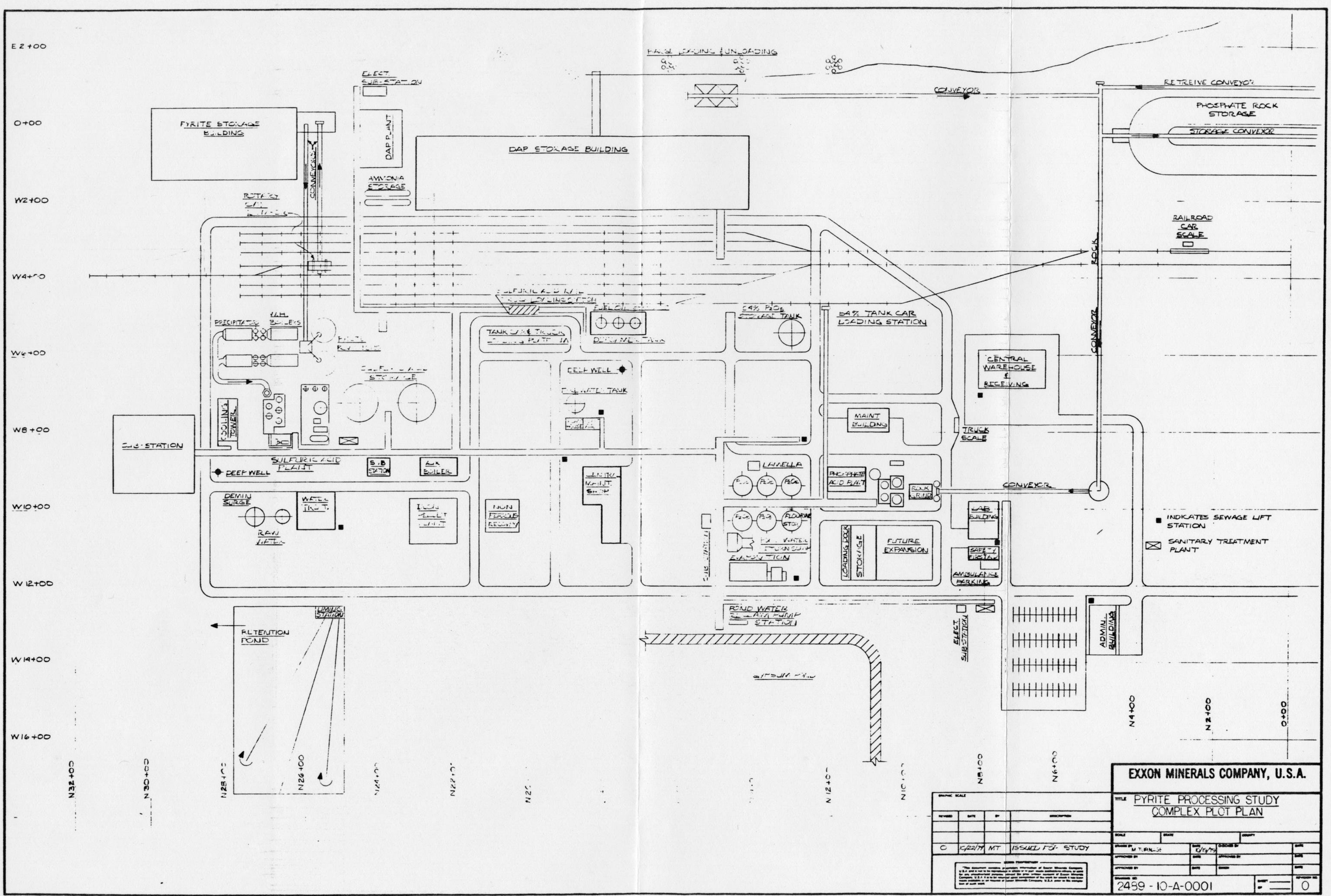
660 TPD METALLURGICAL SULFURIC ACID PLANT



NEW JERSEY ZINC COMPANY

PHOSPHORIC ACID PLANT - 390 TPD

DIAMMONIUM PHOSPHATE PLANT - 900 TPD



EXXON MINERALS COMPANY, U.S.A.

TITLE PYRITE PROCESSING STUDY
COMPLEX PLOT PLAN

REVISED	DATE	BY	DESCRIPTION
0	10/22/79	MT	ISSUED FOR STUDY

DRAWN BY M. TURNAGE DATE 10/19/79

DRAWING NO. 2489 - 10-A-0001 REVISION NO. 0